GROWTH PERFORMANCE AND CARCASS CHARACTERISTICS OF IMMUNOLOGICALLY-CASTRATED BARROWS IN COMPARISON TO INTACT MALES, PHYSICALLY-CASTRATED BARROWS, AND GILTS

BY

CHRISTOPHER LEIGH PULS

DISSERTATION

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Doctoral Committee:

Professor Michael Ellis, Chair
Professor Floyd McKeith
Professor Clifford Shipley
Dr. Beau Peterson, The Maschhoffs, LLC

ABSTRACT

Three studies were conducted to compare the growth performance and carcass characteristics of immunologically-castrated (with Improvest®) barrows relative to other genders. The first study evaluated the growth performance of immunologically- and physically-castrated barrows, intact males, and gilts from wk 16 of age (67.2 ± 2.52 kg BW) to a pen mean BW of 132.5 ± 3.60 kg. The results of this study suggested that immunologically- compared to physically-castrated barrows had greater overall ADG and G:F, but similar overall ADFI. In the period after second Improvest® dose, immunologically-castrated barrows had greater ADG and ADFI than the other genders. The second study evaluated the effect of Gender (physically-and immunologically-castrated barrows, and gilts) and Ractopamine inclusion level (0, 5, and 7.5 mg/kg) on the growth performance and carcass characteristics of pigs from wk 16 of age (69.6 ± 2.96 kg BW) for a fixed-time of 61 d. The results of this study confirmed that immunologically- compared to physically castrated barrows had greater growth performance, but lower carcass yield. In addition, the results of this study confirmed the effects of ractopamine on growth performance and carcass characteristics and suggested that the response to ractopamine is similar in all of the genders. The final study was carried out to evaluate the effects of increasing the time from second Improvest® dose to the end of test on the growth performance and carcass characteristics of immunologically-castrated barrows in comparison to physically-castrated barrows and gilts. Second dose of Improvest® was given at wk 14, 16, 18, or 20 of age, with animals being sent for harvest 4, 6, 8, or 10 wk later. The difference in performance of physically-castrated barrows and gilts was generally in line with expectations. The growth performance of immunologically-castrated barrows became more similar to physically-castrated barrows as the time between second dose and end of test increased. These results suggest that there is no advantage in growth performance from giving second Improvest® dose earlier than 4-

wk prior to harvest. Overall, this research suggests that immunological castration with Improvest® improves growth performance compared to physically-castrated barrows, however, the reduction in carcass yield for immunologically-compared to physically-castrated barrows is of concern and warrants further study.

Keywords: immunological castration; Improvest®; pigs

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IMPROVEST

Introduction

Producing intact males for pork production offers several advantages compared to producing physically-castrated barrows, including greater feed efficiency (Campbell et al., 1989; Bonneau et al., 1994; Pauly et al., 2009) and improved carcass leanness (Dunshea et al., 2001). However, intact males are not currently used in the US because of concerns over boar taint which is the characteristic unpleasant odor that is produced from meat from sexually mature intact males when cooked (Williams et al., 1963; Patterson, 1968; Zamaratskaia et al., 2008). Two compounds, androstenone and skatole, are primarily associated with boar taint and the deposition of these in pork fat increases when intact males reach puberty (Patterson, 1968; Bonneau, 1982; Zamaratskaia et al., 2008). Improvest® (Pfizer Animal Health, Kalamazoo, MI) is an immunological product approved for the immunological castration of intact males and offers producers the growth advantages of producing intact males while also eliminating the risk of boar taint from developing in late-finishing. Improvest®, which is administered in 2 doses at least 4 weeks apart, has been researched extensively around the world; however, study conditions including the weight and age of the pigs used vary greatly from those commonly experienced in the US. This review will focus on the growth performance and carcass characteristics of immunologically-castrated barrows (with Improvest®) in relation to intact males, physically-castrated barrows, and gilts.

Growth Performance of Immunologically-Castrated Barrows Relative to Other Genders

This section will focus on the growth performance of immunologically-castrated barrows relative to other genders for the period from first to second dose and second dose to harvest weights, which has been researched in a number of studies. However, several important differences exist between studies including timing of first and second Improvest® doses, weight ranges used, and lengths of study periods.

Growth Performance from First to Second Improvest® Dose

A total of 5 studies have evaluated the growth rate of immunologically-castrated barrows relative to intact males for the period from first to second Improvest® dose and these are summarized in Table 1.1. In theory, immunologically-castrated barrows are not castrated until they receive the second dose of product, and thus should have similar performance levels compared to intact males in the period from first to second dose (Millet et al., 2011). This was confirmed in 4 of the 5 studies which reported little or no difference in average daily gain, feed intake, or feed efficiency between immunologically-castrated barrows and intact males between first and second dose (Batorek et al., 2012a; Bonneau et al., 1994; Fàbrega et al., 2010; Morales et al., 2010) (Table 1.1). Interestingly, Turkstra et al. (2002) collected blood samples from pigs at the time of second dose and analyzed gonadal sex hormones and concluded that a percentage of pigs may in fact be castrated after receiving only the first dose. Feed efficiency of these pigs was lower compared to pigs that were not castrated until after receiving the second dose. However, these authors used a different adjuvant than is presently used in the Improvest® product, which may have altered the biological activity of the compound and resulted in the unexpected effect of the first Improvest® dose. In the period from first to second Improvest® dose, only the study carried out by Zeng et al. (2002) showed performance differences between the genders reporting greater average daily gain and feed intake for immunologically-castrated barrows compared to intact males.

Growth Performance from Second Improvest® Dose to Harvest

Numerous studies have measured growth performance of immunologically-castrated barrows relative to other genders for the period following the second Improvest® dose and these studies are summarized in Tables 1.2, 1.3, and 1.4.

For the period following the second dose, immunologically-castrated barrows have been shown to have increased growth rate compared to physically-castrated barrows and intact males (Dunshea et al., 2001; Zeng et al., 2002; Zamaratskaia et al., 2008; Pauly et al., 2009; Fàbrega et al., 2010; Dunshea et al., 2011). Some studies, however, have not reported such increases in growth rate. For example, Bonneau et al. (1994) and Morales et al. (2010) reported similar growth rate immunologically-castrated barrows and intact males following the second Improvest® dose (Table 1.2). The increase in growth rate of immunologically-castrated barrows compared to intact males appears to be associated with an increase in feed intake. From second dose at 21 wk of age (86 kg BW) to 115 kg BW, Fàbrega et al. (2010) reported 19.4% and 38.6% greater feed intake for immunologically-castrated barrows compared to physically-castrated barrows and intact males, respectively (Table 1.3). A number of studies, however, reported similar feed intake for immunologically- and physically-castrated barrows following the second dose (Batorek et al., 2012a; Bonneau et al., 1994; Pauly et al., 2009; Morales et al., 2010; Morales et al., 2011; Morales et al., 2013). Interestingly, it appears that when feed intake is fixed, growth performance of immunologically-castrated barrows may be similar to that of physically-castrated barrows. Andersson et al. (2012) evaluated physically- and immunologically-castrated barrows, and intact males, under a restricted feeding regime and concluded that when feed intake was restricted to the same level for all genders, there were no differences in growth rate or feed conversion ratio for the different genders. In contrast, Metz et al. (2002) restricted feed intake and showed that intact males had greater growth rate and greater feed conversion than immunologically-castrated and physically-castrated barrows, which were similar for these traits. Under *ad libitum* feeding conditions, numerous studies have shown greater feed efficiency for immunologically-castrated barrows compared to physically-castrated barrows from second Improvest® dose to harvest weights (Bonneau et al., 1994; Dunshea et al., 2001; Pauly et al., 2009; Fàbrega et al., 2010; Morales et al., 2013) (Table 1.4). In addition, a number of studies have shown immunologically-castrated barrows had similar feed efficiency for the same period compared to intact males (Bonneau et al., 1994; Dunshea et al., 2001; Pauly et al., 2009; Fàbrega et al., 2010; Dunshea et al., 2011). This variation between studies in the differences between genders for growth performance variables may be due, at least in part, to differences in the methodology used, including the weight of pigs used and timing of the second dose.

Growth Performance of Physically-Castrated Barrows, Intact Males, and Gilts

A number of studies have evaluated the growth performance of physically-castrated barrows, intact males, and gilts. Differences have been reported between the genders for growth rate, feed intake, and feed efficiency. Some studies have shown that gilts generally grow slower than intact males and physically-castrated barrows (Dunshea et al., 1993; Cisneros et al., 1996; Hamilton et al., 2003; Oliver et al., 2003). Physically-castrated barrows had greater feed intake than intact males and gilts in a number of studies (Dunshea et al., 1993; Bonneau et al., 1994; Cisneros et al., 1996; Hamilton et al., 2003; Latorre et al., 2004). In addition, intact males have demonstrated greater feed efficiency compared to physically-castrated barrows and gilts (Campbell et al., 1989; Dunshea et al., 1993; Dunshea et al., 1998; Pauly et al., 2009). Some studies reported greater feed efficiency for gilts compared to physically-castrated barrows

(Hamilton et al., 2003; Latorre et al., 2004; Fàbrega et al., 2010). Due to these performance differences, pigs of the different genders may need to be reared independently, with different nutritional and management programs, in order to maximize growth.

Carcass Characteristics of Immunologically-Castrated Barrows Relative to Other Genders

Carcass Yield of Immunologically-castrated Barrows Relative to Other Genders

Studies that have reported carcass yield differences between immunologically-castrated barrows and physically-castrated barrows, intact males, and gilts are summarized in Table 1.5. A number of studies have reported lower carcass yield for immunologically-castrated barrows compared to physically-castrated barrows (Bonneau et al., 1994; Dunshea et al., 2001; Zamaratskaia et al., 2008; Fuchs et al., 2009; Fàbrega et al., 2010; Boler et al., 2012). Interestingly, some studies have also reported lower carcass yield for immunologically-castrated barrows compared to intact males (Zamaratskaia et al., 2008; Gispert et al., 2010; Dunshea et al., 2011), which suggests that factors other than the weight of the reproductive tract and testes may be contributing to lower carcass yield observed in immunologically-castrated barrows. Dunshea et al. (2001) suggested that the decrease in yield for immunologically-castrated barrows from intact males may be due to greater feed intake and, thus, greater gut fill. Additionally, those authors suggested that the reduction in carcass yield for immunologically-castrated barrows relative to physically-castrated barrows and intact males may be age dependent. In that study, pigs were administered the second dose of Improvest® at either wk 19 or 22 of age and sent for harvest at wk 23 and 26 of age, respectively. Pigs that received the second dose at wk 19 of age had a 0.1 percentage unit lower carcass yield than intact males. In contrast, pigs that received the second dose at wk 22 of age had a 1.3 percentage unit lower carcass yield than intact males (Dunshea et al., 2001). In addition, Pauly et al. (2009) reported numerically greater liver and kidney weights for immunologically-castrated barrows compared to intact males, which may also contribute to the reduced carcass yield seen in these animals. Boler et al. (2013) reported that gut fill, testicles, reproductive tract, intestinal mass, and liver and kidney weights were significantly heavier for immunologically-castrated barrows than physically-castrated barrows, and that the sum of these parts accounted for 1 percentage unit difference in carcass yield between immunologically- and physically-castrated barrows.

Strategies to Improve Carcass Yield in Immunologically-Castrated Barrows

Carcass yield is a large economic driver in any pork production system, and any reduction in carcass yield is likely to have implications on the overall profitability of an operation. For example, if a producer is sending pigs for harvest with a desired carcass weight, and carcass yield declines, the pig must remain in the facility for an additional period of time in order to achieve the targeted carcass weight which results in greater feed consumption and longer times for facilities to empty. Therefore, strategies that may improve carcass yield of immunologically-castrated barrows must be evaluated in an attempt to alleviate the carcass yield disadvantage of this gender. One such strategy is increasing the time between the second Improvest® dose and harvest. Lealiifano et al. (2011) carried out a study in which immunologically-castrated barrows were administered the second dose of Improvest® either 2, 3, 4, or 6 wk prior to harvest. Those authors concluded that the weight of the testicles decreased linearly with increasing amount of time between second dose and harvest. However, in that study, carcass yield was not affected by timing of second dose. Average daily feed intake increased with increasing time between second dose and harvest and may have contributed to an increase in gut fill as discussed previously, although this was not measured in that study.

Backfat Thickness of Immunologically-Castrated Barrows Relative to Other Genders

Studies that have reported backfat thickness differences between immunologically- and physically-castrated barrows, intact males, and gilts are summarized in Table 1.6. Immunologically-castrated barrows have been shown to have greater backfat thickness than intact males in a number of studies (D'Souza and Mullan, 2003; Pauly et al., 2009; Fàbrega et al., 2010; Gispert et al., 2010). In addition, backfat thickness has generally been shown to be greater for physically-castrated barrows compared to immunologically-castrated barrows (Dunshea et al., 2001; Fuchs et al., 2009; Pauly et al., 2009; Morales et al., 2011). However, end of test weight differences for the genders both within and between studies is likely to impact observed differences in backfat thickness as backfat thickness has been shown to increase with increasing harvest weight (Cisneros et al., 1996; Latorre et al., 2004).

Other Considerations of Immunologically-Castrated Barrows

Aggressive and Sexual Behavior

Relatively few studies have evaluated the behavior of immunologically-castrated barrows relative to physically-castrated barrows and intact males. Generally speaking, the behavior of immunologically-castrated barrows prior to second Improvest® dose is similar to that of intact males, and behavior in the period following second Improvest® dose is similar to that of physically-castrated barrows (Cronin et al., 2003; Fàbrega et al., 2010; Rydhmer et al., 2010; Andersson et al., 2012). Intact males spend more time performing sexual behaviors compared to physically-castrated barrows including greater frequency of sexual mounts (Fàbrega et al., 2010; Andersson et al., 2012). Additionally, Baumgartner et al. (2010) reported that in the period prior to second Improvest® dose, immunologically-castrated barrows spend more time standing, biting and fighting, and mounting compared to physically-castrated barrows. However, in the weeks following second dose, the frequency of these behaviors declined and the time spent lying increased for immunologically-castrated barrows and were not different than physically-castrated males (Baumgartner et al., 2010). In addition, Rydhmer et al. (2010) suggested that the behavior of immunologically-castrated barrows transitions from being similar to that of an intact male to that of physically-castrated barrows within the first week following the second Improvest® dose, results which are similar to a study carried out by our research group (Puls et al., 2013).

Effects of Immunological Castration on the Incidence of Boar Taint

Boar taint is the characteristic unpleasant odor that is produced from meat from sexually mature intact males when cooked (Williams, et al., 1963; Patterson, 1968; Zamaratskaia et al., 2008). The compounds androstenone and skatole are primarily associated with boar taint and these compounds increase in concentration in pork fat as males become sexually mature (Patterson, 1968; Bonneau, 1982; Zamaratskaia et al., 2008). Androstenone is described as a urine-like odor where skatole is described as a fecal-like odor. Due to the concern for boar taint and the unpleasant experience for the consumer, intact males are not currently used for pork production in the US. Immunological-castration with Improvest® has been shown to reduce the levels of androstenone and skatole in pork fat, and thus reduce the incidence of boar taint to levels of physically-castrated barrows (Dunshea et al., 2001; Font-i-Furnols et al., 2009; Batorek et al., 2012b).

RACTOPAMINE

Introduction

Ractopamine hydrochloride (Paylean®, Elanco Animal Health, Greenfield, IN) is a beta-agonist that is used in late-finishing swine diets to improve growth performance and carcass leanness. This section will focus on the effects of ractopamine on the growth performance and carcass characteristics of pigs.

Effects of Ractopamine on Growth Performance

The effects of ractopamine on pig growth performance have been evaluated in a number of studies. Feeding ractopamine has been shown to increase growth rate (Watkins et al., 1990; Stites et al., 1991; Patience et al., 2009; Puls et al., 2010) and feed efficiency (Stites et al., 1991; Uttaro et al., 1993; Armstrong et al., 2004). Furthermore, Apple et al. (2007) carried out a meta-analysis evaluating the effects of feeding ractopamine and concluded that feeding 5 ppm ractopamine increased growth rate and feed efficiency by 12% and 10%, respectively.

Effects of Ractopamine on Carcass Characteristics

Feeding ractopamine to late-finishing pigs has been shown to increase carcass yield (Watkins et al., 1990; Stites et al., 1991; Armstrong et al., 2004) and decrease backfat thickness (Uttaro et al., 1993). Apple et al. (2007) reported that feeding ractopamine at 0, 5, 10, and 20 ppm resulted in backfat thickness of 2.34, 2.30, 2.20, and 2.11 cm, respectively. In addition, fat-free lean percentage increased with increasing ractopamine inclusion level (Apple et al., 2007).

CONCLUSIONS

Immunologically-castrated barrows have been shown to have similar growth performance to intact males from first to second dose, and have increased growth and feed intake relative to other genders following the second dose. However, many of the studies evaluating the growth performance of immunologically-castrated barrows have used harvest weights considerably lighter than commonly used in the US. Therefore, there is a need for further research to investigate the growth performance of the genders to heavier weights (~130 kg) and, also, in combination with other technologies that can be used in late-finishing (e.g., Ractopamine). In addition, several questions still remain around the growth of immunologically-castrated barrows. Firstly, research that is available to describe the growth of immunologically-castrated barrows from birth to first Improvest® dose relative to physically-castrated barrows and gilts is outdated and no longer applicable to modern production systems. Secondly, much of the research carried out with immunologically-castrated barrows evaluated growth of animals to only 4 weeks post-second dose. It is likely that in commercial practice that all animals will be administered the second dose at one time, and pigs will be sent for harvest over several weeks. Thus, it is important to understand the growth curve of immunologically-castrated barrows from birth to the harvest weights that may be used. The results of this research could greatly benefit producers in understanding the effects of Improvest® on growth performance.

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TABLES

Table 1.1. Summary of studies evaluating growth performance of immunologically-castrated barrows relative to other genders in the period from first to second Improvest® dose.

Item	# Pigs	Age range	BW range	First dose	Second dose	Housing system	Feed regime	Gender[1] PC	IC	IM	G	*P*-value
Average daily gain, kg/d												
Batorek et al., 2012b	64	83-165 d	28-110 kg	83 d	130 d	Individual	Ad libitum	0.96	0.93	0.88	-	0.06
Bonneau et al., 1994	60	-	29-105 kg	29 kg	89 kg	Individual	Ad libitum	0.90	0.90	0.87	-	0.20
Fàbrega et al., 2010	150	10-26 wk	28-115 kg	11 wk	86 kg (21 wk)	Pen (15)	Ad libitum	0.93[a]	0.84[b]	0.84[b]	0.87[ab]	<0.05
Morales et al., 2010	288	10-25 wk	31-110 kg	10 wk (74 d)	89 kg (145 d)	Pen (8)	Ad libitum	0.81	0.81	0.80	0.78	>0.05
Zeng et al., 2002	60	10-110 kg	NA[2]-110 kg	10 wk	17 wk	Pen (6)	Ad libitum	0.81[a]	0.79[a]	0.73[b]	-	0.04
Average daily feed intake, kg/d												
Batorek et al., 2012b	64	83-165 d	28-110 kg	83 d	130 d	Individual	Ad libitum	2.30[a]	2.04[b]	1.98[b]	-	<0.001
Bonneau et al., 1994	60	-	29-105 kg	29 kg	89 kg	Individual	Ad libitum	2.42[a]	2.20[b]	2.14[b]	-	<0.001
Fàbrega et al., 2010	150	10-26 wk	28-115 kg	11 wk	86 kg (21 wk)	Pen (15)	Ad libitum	2.14[a]	1.76[b]	1.77[b]	1.87[b]	<0.05
Morales et al., 2010	288	10-25 wk	31-110 kg	10 wk (74 d)	89 kg (145 d)	Pen (8)	Ad libitum	2.06[a]	1.94[b]	1.85[b]	1.91[b]	<0.05
Zeng et al., 2002	60	10-110 kg	NA[2]-110 kg	10 wk	17 wk	Pen (6)	Ad libitum	1.90	1.77	1.61	-	0.06
Gain:Feed, kg/kg												
Batorek et al., 2012b	64	83-165 d	28-110 kg	83 d	130 d	Individual	Ad libitum	0.42[b]	0.45[a]	0.44[ab]	-	0.01
Bonneau et al., 1994	60	-	29-105 kg	29 kg	89 kg	Individual	Ad libitum	0.37[b]	0.41[a]	0.41[a]	-	<0.001
Fàbrega et al., 2010	150	10-26 wk	28-115 kg	11 wk	86 kg (21 wk)	Pen (15)	Ad libitum	0.43[b]	0.48[a]	0.47[a]	0.46[a]	<0.05
Morales et al., 2010	288	10-25 wk	31-110 kg	10 wk (74 d)	89 kg (145 d)	Pen (8)	Ad libitum	0.39[c]	0.42[ab]	0.43[a]	0.41[b]	<0.05

[1]Gender: PC = Physically-castrated barrow; IC = Immunologically-castrated barrow; IM = Intact male; G = Gilt.

[2]NA = Not applicable or not given.

[a,b,c]Means with different superscripts are statistically different.

Table 1.2. Summary of studies evaluating average daily gain of immunologically-castrated barrows relative to other genders in the period from second Improvest® dose to harvest.

Item	# pigs	Age range	BW range	Second dose	Harvest weight and age	Housing system	Feed regime	Gender[1]				*P*-value
								PC	IC	IM	G	
Average daily gain, kg/d												
Batorek et al., 2012a	64	83-165 d	28-110 kg	83 d	110 kg (130 d)	Individual	Ad libitum	0.94^{b}	1.13^{a}	0.96^{b}	-	0.001
Bonneau et al., 1994	60	-	29-105 kg	89 d	105 kg	Individual	Ad libitum	1.02^{b}	1.16^{a}	1.15^{a}	-	0.01
Dunshea et al., 2001	300	-	52-97 kg	75 kg (19 wk)	97 kg (23 wk)	Pen (20)	Ad libitum	0.81	0.87	0.79	-	0.05
Dunshea et al., 2001	300	-	52-115 kg	90 kg (22 wk)	115 kg (26 wk)	Pen (20)	Ad libitum	0.85^{b}	1.12^{a}	0.86^{b}	-	<0.001
Dunshea et al., 2011	300	14-23 wk	49-105 kg	18 wk	105 kg (23 wk)	Pen (15)	Ad libitum	0.94^{b}	1.09^{a}	0.91^{b}	-	<0.001
Fàbrega et al., 2010	150	10-26 wk	28-115 kg	86 kg (21 wk)	115 kg (26 wk)	Pen (15)	Ad libitum	0.84^{b}	1.16^{a}	0.83^{b}	0.68^{c}	<0.05
Font-i-Furnols et al., 2012	75	12-31 wk	32-140 kg	105 kg (172 d)	139 kg (215 d)	Pen (9)	Ad libitum	0.77^{b}	0.91^{a}	-	0.77^{b}	<0.05
McCauley et al., 2003	48	14-22 wk	80-115 kg	18 wk	115 kg (22 wk)	Individual	Ad libitum	-	1.24	1.38	1.07	<0.05
Morales et al., 2010	288	10-25 wk	31-110 kg	89 kg (145 d)	108 kg (172 d)	Pen (8)	Ad libitum	0.88^{a}	0.95^{a}	0.90^{a}	0.77^{b}	<0.05
Morales et al., 2011	360	9-25 wk	20-127 kg	18 wk (126 d)	127 kg (25 wk)	Pen (10)	Ad libitum	0.93^{b}	1.05^{a}	-	0.93^{b}	<0.05
Morales et al., 2013	240	87-164 d	42-125 kg	137 d	125 kg (164 d)	Pen (8)	Ad libitum	1.03^{b}	1.18^{a}	-	1.00^{b}	<0.001
Oliver et al., 2003	224	17-21 wk	65-100 kg	17 wk	100 kg (21 wk)	Pen (7)	Ad libitum	-	1.32^{a}	1.22^{b}	0.99^{c}	<0.05
Pauly et al., 2009	39	10 wk-105 kg	27-105 kg	19 wk (131 d)	105 kg	Pen (13)	Ad libitum	1.01^{b}	1.14^{a}	1.03^{b}	-	<0.05
Zamaratskaia et al., 2008	120	10-24 wk	26-124 kg	20 wk (89 kg)	124 kg (167 d)	Pen (8)	Ad libitum	1.09^{b}	1.26^{a}	1.11^{b}	-	0.01
Zeng et al., 2002	60	10-110 kg	10-110 kg	17 wk	110 kg (25 wk)	Pen (6)	Ad libitum	1.03^{b}	1.14^{a}	1.00^{b}	-	0.03

[1]Gender: PC = Physically-castrated barrow; IC = Immunologically-castrated barrow; IM = Intact male; G = Gilt.

[a,b,c]Means with different superscripts are statistically different.

Table 1.3. Summary of studies evaluating average daily feed intake of immunologically-castrated barrows relative to other genders in the period from second Improvest® dose to harvest.

Item	# pigs	Age range	BW range	Second dose	Harvest weight and age	Housing system	Feed regime	Gender[1] PC	IC	IM	G	*P*-value
Average daily feed intake, kg/d												
Batorek et al., 2012a	64	83-165 d	28-110 kg	83 d	110 kg (130 d)	Individual	Ad libitum	3.46[a]	3.52[a]	3.11[b]	-	<0.001
Bonneau et al., 1994	60	-	29-105 kg	89 d	105 kg	Individual	Ad libitum	3.54	3.31	3.27	-	0.10
Dunshea et al., 2001	300	-	52-97 kg	75 kg (19 wk)	97 kg (23 wk)	Pen (20)	Ad libitum	2.91[a]	2.81[a]	2.44[b]	-	0.01
Dunshea et al., 2001	300	-	52-115 kg	90 kg (22 wk)	115 kg (26 wk)	Pen (20)	Ad libitum	3.13	3.40	2.79	-	0.10
Dunshea et al., 2011	300	14-23 wk	49-105 kg	18 wk	105 kg (23 wk)	Pen (15)	Ad libitum	2.87[ab]	3.07[a]	2.52[b]	-	<0.001
Fàbrega et al., 2010	150	10-26 wk	28-115 kg	86 kg (21 wk)	115 kg (26 wk)	Pen (15)	Ad libitum	2.89[b]	3.45[a]	2.49[c]	2.42[c]	<0.05
Morales et al., 2010	288	10-25 wk	31-110 kg	89 kg (145 d)	108 kg (172 d)	Pen (8)	Ad libitum	2.92[a]	2.94[a]	2.54[b]	2.49[b]	<0.05
Morales et al., 2011	360	9-25 wk	20-127 kg	18 wk (126 d)	127 kg (25 wk)	Pen (10)	Ad libitum	3.26[a]	3.26[a]	-	3.08[b]	<0.05
Morales et al., 2013	240	87-164 d	42-125 kg	137 d	125 kg (164 d)	Pen (8)	Ad libitum	3.43[a]	3.41[a]	-	3.09[b]	<0.001
Oliver et al., 2003	224	17-21 wk	65-100 kg	17 wk	100 kg (21 wk)	Pen (7)	Ad libitum	-	3.34[a]	2.95[b]	2.69[c]	<0.05
Pauly et al., 2009	39	10 wk-105 kg	27-105 kg	19 wk (131 d)	105 kg	Pen (13)	Ad libitum	3.09[a]	3.10[a]	2.62[b]	-	<0.05
Zeng et al., 2002	60	10-110 kg	10-110 kg	17 wk	110 kg (25 wk)	Pen (6)	Ad libitum	2.99	3.17	2.56		0.09

[1]Gender: PC = Physically-castrated barrow; IC = Immunologically-castrated barrow; IM = Intact male; G = Gilt.

[a,b,c]Means with different superscripts are statistically different.

Table 1.4. Summary of studies evaluating gain:feed ratio of immunologically-castrated barrows relative to other genders in the period from second Improvest® dose to harvest.

Item	# pigs	Age range	BW range	Second dose	Harvest weight and age	Housing system	Feed regime	Gender[1] PC	IC	IM	G	*P*-value
Gain:Feed, kg/kg												
Batorek et al., 2012a	64	83-165 d	28-110 kg	83 d	110 kg (130 d)	Individual	Ad libitum	0.26^{b}	0.32^{a}	0.30^{a}	-	<0.001
Bonneau et al., 1994	60	-	29-105 kg	89 d	105 kg	Individual	Ad libitum	0.29^{b}	0.35^{a}	0.35^{a}	-	<0.001
Dunshea et al., 2001	300	-	52-97 kg	75 kg (19 wk)	97 kg (23 wk)	Pen (20)	Ad libitum	0.29^{b}	0.33^{a}	0.33^{a}	-	0.02
Dunshea et al., 2001	300	-	52-115 kg	90 kg (22 wk)	115 kg (26 wk)	Pen (20)	Ad libitum	0.27^{b}	0.32^{a}	0.30^{ab}	-	0.04
Dunshea et al., 2011	300	14-23 wk	49-105 kg	18 wk	105 kg (23 wk)	Pen (15)	Ad libitum	0.33^{b}	0.36^{a}	0.36^{a}	-	0.02
Fàbrega et al., 2010	150	10-26 wk	28-115 kg	86 kg (21 wk)	115 kg (26 wk)	Pen (15)	Ad libitum	0.29^{b}	0.34^{a}	0.31^{a}	0.26^{b}	<0.05
McCauley et al., 2003	48	14-22 wk	80-115 kg	18 wk	115 kg (22 wk)	Individual	Ad libitum	-	0.32	0.38	0.30	<0.05
Morales et al., 2010	288	10-25 wk	31-110 kg	89 kg (145 d)	108 kg (172 d)	Pen (8)	Ad libitum	0.30^{b}	0.32^{ab}	0.35^{a}	0.31^{b}	<0.05
Morales et al., 2011	360	9-25 wk	20-127 kg	18 wk (126 d)	127 kg (25 wk)	Pen (10)	Ad libitum	0.29^{b}	0.32^{a}	-	0.30^{b}	<0.05
Morales et al., 2013	240	87-164 d	42-125 kg	137 d	125 kg (164 d)	Pen (8)	Ad libitum	0.30^{c}	0.35^{a}	-	0.32^{b}	<0.001
Oliver et al., 2003	224	17-21 wk	65-100 kg	17 wk	100 kg (21 wk)	Pen (7)	Ad libitum	-	0.40^{a}	0.41^{a}	0.37^{b}	<0.05
Pauly et al., 2009	39	10 wk-105 kg	27-105 kg	19 wk (131 d)	105 kg	Pen (13)	Ad libitum	0.32^{b}	0.36^{a}	0.39^{a}	-	<0.05

[1]Gender: PC = Physically-castrated barrow; IC = Immunologically-castrated barrow; IM = Intact male; G = Gilt.

[a,b,c]Means with different superscripts are statistically different.

Table 1.5. Summary of studies evaluating carcass yield of immunologically-castrated barrows relative to other genders.

Item	# pigs	First dose	Second dose	Harvest weight and age	Housing system	Feed regime	Gender[1]				*P*-value
							PC	IC	IM	G	
Carcass yield, %											
Batorek et al., 2012a	64	83 d	130 d	110 kg	Individual	Ad libitum	79.6	77.3	78.4	-	-
Boler et al., 2012	156	15 wk	19 wk	23 or 25 wk	Pen (25)	Ad libitum	74.5[a]	71.8[b]	-	-	<0.001
Boler et al., 2013	180	16 wk	20 wk	130 kg (~24 wk)	Pen (4)	Ad libitum	78.7[a]	77.3[b]	77.4[b]	78.5[a]	<0.001
Bonneau et al., 1994	60	29 kg	89 d	105 kg	Individual	Ad libitum	87.5[a]	85.3[b]	85.8[b]	-	0.002
D'Souza and Mullan, 2003	60	10 wk	4 wk pre-harv	106 kg	Individual	Ad libitum	70.6	70.0	69.5	-	>0.05
Dunshea et al., 2001	300	52 kg (15 wk)	75 kg (19 wk)	97 kg (23 wk)	Pen (20)	Ad libitum	77.1[a]	75.7[b]	75.8[b]	-	<0.01
Dunshea et al., 2001	300	18 wk	90 kg (22 wk)	115 kg (26 wk)	Pen (20)	Ad libitum	79.3[a]	76.8[c]	78.1[b]	-	<0.01
Dunshea et al., 2011	300	14 wk	18 wk	105 kg (23 wk)	Pen (15)	Ad libitum	79.1[a]	77.4[b]	78.1[b]	-	0.02
Fàbrega et al., 2010	150	11 wk	86 kg (21 wk)	115 kg (26 wk)	Pen (15)	Ad libitum	76.9[a]	73.0[c]	-	75.7[b]	<0.05
Fuchs et al., 2009	554	13-14 wk	20-21 wk	24-26 wk	-	-	79.4[a]	77.9[b]	-	-	<0.001
Gispert et al., 2010	120	11 wk	21 wk	25-26 wk	Pen (12)	Ad libitum	80.8[a]	78.7[c]	79.8[b]	81.0[a]	<0.001
McCauley et al., 2003	48	14 wk	18 wk	115 kg (22 wk)	Individual	Ad libitum	-	80.7[b]	80.8[b]	82.1[a]	<0.05
Morales et al., 2010	288	10 wk (74 d)	89 kg (145 d)	108 kg (172 d)	Pen (8)	Ad libitum	76.7[a]	75.5[b]	76.1[b]	77.5[a]	<0.05
Morales et al., 2011	360	11 wk (78 d)	18 wk (126 d)	127 kg (25 wk)	Pen (10)	Ad libitum	78.7[a]	77.2[b]	-	79.1[a]	0.001
Morales et al., 2013	240	87 d	137 d	125 kg (164 d)	Pen (8)	Ad libitum	78.1[b]	76.6[c]	-	78.8[a]	<0.001
Oliver et al., 2003	224	13 wk	17 wk	100 kg (21 wk)	Pen (7)	Ad libitum	-	75.7[c]	77.6[b]	79.5[a]	<0.05
Pauly et al., 2009	39	9 wk (67 d)	19 wk (131 d)	105 kg	Pen (13)	Ad libitum	79.5[a]	78.3[b]	78.6[b]	-	<0.05
Turkstra et al., 2002	48	9 wk	17 wk	110 kg	Pen (3)	Restricted	76.1[a]	75.2[b]	75.5[ab]	-	<0.05
Zamaratskaia et al., 2008	120	16 wk (111 d)	20 wk (89 kg)	124 kg (167 d)	Pen (8)	Ad libitum	75.3[a]	73.5[b]	74.7[a]	-	0.01
Zeng et al., 2002	60	10 wk	17 wk	110 kg	Pen (6)	Ad libitum	76.7	76.3	75.2		0.56

[1]Gender: PC = Physically-castrated barrow; IC = Immunologically-castrated barrow; IM = Intact male; G = Gilt.

[a,b,c]Means with different superscripts are statistically different.

Table 1.6. Summary of studies evaluating backfat thickness of immunologically-castrated barrows relative to other genders.

Item	# pigs	First dose	Second dose	Harvest weight and age	Housing system	Feed regime	Gender[1]				*P*-value
							PC	IC	IM	G	
Backfat thickness, mm											
Batorek et al., 2012a	64	83 d	130 d	110 kg	Individual	Ad libitum	14.8^{a}	12.9^{a}	9.8^{b}	-	<0.001
Boler et al., 2012	156	15 wk	19 wk	23 or 25 wk	Pen (25)	Ad libitum	17.7^{a}	16.3^{b}	-	-	0.01
Boler et al., 2013	180	16 wk	20 wk	130 kg (~24 wk)	Pen (4)	Ad libitum	25.2^{a}	24.3^{a}	18.2^{c}	21.1^{b}	<0.001
D'Souza and Mullan, 2003	60	10 wk	4 wk pre-harvest	106 kg	Individual	Ad libitum	23.2^{a}	24.0^{a}	20.9^{b}	-	<0.05
Dunshea et al., 2001	300	52 kg (15 wk)	75 kg (19 wk)	97 kg (23 wk)	Pen (20)	Ad libitum	14.4^{a}	11.9^{b}	11.1^{b}	-	<0.001
Dunshea et al., 2001	300	18 wk	90 kg (22 wk)	115 kg (26 wk)	Pen (20)	Ad libitum	17.1^{a}	15.1^{b}	12.6^{c}	-	<0.001
Fàbrega et al., 2010	150	11 wk	86 kg (21 wk)	115 kg (26 wk)	Pen (15)	Ad libitum	15.0^{a}	13.2^{a}	10.2^{b}	11.5^{b}	<0.05
Font-i-Furnols et al., 2012	75	32 kg (88 d)	105 kg (172 d)	139 kg (215 d)	Pen (9)	Ad libitum	31.3^{a}	29.0^{ab}	-	26.0^{b}	<0.05
Fuchs et al., 2009	554	13-14 wk	20-21 wk	24-26 wk	-	-	17.3^{a}	15.6^{b}	-	-	<0.001
Gispert et al., 2010	120	11 wk	21 wk	25-26 wk	Pen (12)	Ad libitum	20.5^{a}	19.7^{a}	15.2^{b}	16.1^{b}	<0.001
McCauley et al., 2003	48	14 wk	18 wk	115 kg (22 wk)	Individual	Ad libitum	-	19.7^{a}	20.0^{a}	18.6^{b}	<0.05
Metz et al., 2002	26	10 wk	16 wk	116 kg (26 wk)	Individual	Restricted	18.5^{a}	19.0^{a}	15.5^{b}	-	<0.01
Morales et al., 2010	288	10 wk (74 d)	89 kg (145 d)	108 kg (172 d)	Pen (8)	Ad libitum	19.3^{a}	17.6^{ab}	16.2^{b}	16.6^{b}	<0.05
Morales et al., 2011	360	11 wk (78 d)	18 wk (126 d)	127 kg (25 wk)	Pen (10)	Ad libitum	26.4^{a}	23.3^{b}	-	24.3^{b}	0.001
Morales et al., 2013	240	87 d	137 d	125 kg (164 d)	Pen (8)	Ad libitum	28.7^{a}	26.1^{b}	-	26.6^{b}	<0.001
Oliver et al., 2003	224	13 wk	17 wk	100 kg (21 wk)	Pen (7)	Ad libitum	-	17.0^{a}	14.7^{b}	14.2^{b}	<0.05
Pauly et al., 2009	39	9 wk (67 d)	19 wk (131 d)	105 kg	Pen (13)	Ad libitum	24.9^{a}	19.3^{b}	17.8c	-	<0.05
Turkstra et al., 2002	48	9 wk	17 wk	110 kg	Pen (3)	Restricted	13.5	12.6	13.0	-	>0.05

[1]Gender: PC = Physically-castrated barrows; IC = Immunologically-castrated barrows; IM = Intact males; G = Gilts.

[a,b,c]Means with different superscripts are statistically different.

CHAPTER 2: GROWTH PERFORMANCE OF IMMUNOLOGICALLY-CASTRATED (WITH IMPROVEST®) BARROWS (WITH OR WITHOUT RACTOPAMINE) COMPARED TO GILT, PHYSICALLY-CASTRATED BARROW, AND INTACT MALE PIGS.

ABSTRACT

The study was carried out using a randomized complete block design (blocking factor was date of start on test) with 5 treatments: 1) Physically-castrated barrows (PC), 2) Intact males (IM), 3) Gilts (G), 4) Immunologically-castrated barrows (IC), and 5) Immunologically-castrated barrows fed ractopamine at 5 ppm (IC+RAC). The study used 192 pigs and was carried out from the first Improvest® dose (2 Ml of product) (approximately 16 wk of age; 67.2 ± 2.52 kg BW) to a pen mean BW of 132.5 ± 3.60 kg. The second Improvest® dose (2 Ml) was given 4 wk later. For IC+RAC, ractopamine was fed from 1 wk after second dose to the end of the study. Pigs were housed in groups of 4 (10 groups for PC, IM, G, and IC and 8 groups for IC+RAC) in a finishing building at a floor space of 1.18 m^2/pig. Diets were formulated to meet the requirements of IM, except that the diet for the IC+RAC fed during the ractopamine feeding period was formulated to meet the requirements of pigs on that treatment. Pigs had *ad libitum* access to feed and water throughout the study period and were individually weighed at start, wk 2 and 4, and, subsequently, pigs were weighed every wk until the end of study. For the overall study period, IC had greater ($P \leq 0.05$) ADG compared to the other genders (1150, 1024, 1064, and 954 g/d for IC, PC, IM, and G, respectively; SEM = 25.8) and required fewer days to reach slaughter weight than the other genders (58.1, 61.6, 61.6, and 66.5 d for IC, PC, IM, and G, respectively; SEM = 1.26). Overall ADFI was less ($P \leq 0.05$) for IM and G than IC and PC, which were similar ($P > 0.05$) in this respect (3.11, 3.06, 2.68, and 2.75 kg/d for IC, PC, IM, and G, respectively; SEM = 0.061). Overall G:F was greater ($P \leq 0.05$) for IM than the other

genders; IC had greater overall G:F than PC and G, which were similar in this respect (0.371, 0.335, 0.397, and 0.347 kg/kg for IC, PC, IM, and G, respectively; SEM = 0.0068). Immunologically-castrated barrows had greater ($P \leq 0.05$) ADG (30.7%) and ADFI (22.5%) than PC from the second wk following the second Improvest® dose to the end of the study. During the ractopamine feeding period, IC+RAC had greater ($P \leq 0.05$) ADG (11.6%) and G:F (17.3%) than IC. The results of this study confirmed previously observed gender differences and effects of ractopamine on growth performance and that IC grew faster and had greater feed efficiency than PC from first Improvest® dose to harvest weight.

INTRODUCTION

Using intact males rather than physically-castrated barrows for pork production would result in greater feed efficiency and improved carcass leanness (Campbell et al., 1989; Dunshea et al., 2001; Pauly et al., 2009). The major limitation to raising intact males is the potential to produce pork with a high incidence of boar taint, the unpleasant odor released when meat from some intact males is cooked (Williams, et al., 1963; Patterson, 1968). Countries that currently produce intact males, such as the United Kingdom and Australia, minimize the risk of boar taint with varying success by harvesting pigs at relatively young ages and light weights. However, in most countries male pigs are physically castrated early in life to eliminate the risk of boar taint. Improvest® (Zoetis, Kalamazoo, MI), a product that immunologically castrates male pigs, has been approved for use in a number of countries including the US. This product is given in 2 doses with the second dose, which is generally given in late finishing, effectively castrating the male. Using Improvest® would allow producers to exploit the growth performance advantages of the intact male early in the growth period while greatly reducing the risk of boar taint developing later. However, most published studies with Improvest® have been carried out to harvest weights that are considerably lighter than those used in the US.

Ractopamine (Paylean, Elanco Animal Health, Greenfield, IN) has been used extensively in the late-finishing period to improve growth rate, feed efficiency, and carcass leanness (Apple et al., 2007). However, there is little research evaluating the impact of feeding ractopamine to immunologically-castrated barrows at heavy weights. Therefore, the objective of this study was to compare the growth performance of immunologically-castrated barrows (with or without ractopamine) and other genders to relatively heavy harvest live weights.

MATERIALS AND METHODS

The study was conducted at the Swine Research Center of the University of Illinois and the experimental protocol for the study was approved by the University of Illinois Institutional Animal Care and Use Committee.

Experimental Design and Treatments

The growth study was conducted as a randomized complete block design with 5 treatments: 1) Physically-castrated barrows (PC), 2) Intact males (IM), 3) Gilts (G), 4) Immunologically-castrated barrows (IC), and 5) Immunologically-castrated barrows fed ractopamine (at 5 ppm; Paylean 9, Elanco Animal Health, Greenfield, IN) (IC+RAC). Date of start on the study was used as the blocking factor. The study was carried out from a fixed time (approximately 16-wk of age; 67.2 ± 2.52 kg BW) to a pen mean BW of 132.5 ± 3.60 kg.

First and second doses (2 Ml of product) of Improvest® (Zoetis, Kalamazoo, MI) were given at the start of study (wk 16 of age) and 4 wk later (d 28 of study), respectively. Improvest® was administered via subcutaneous injection behind and below the base of the ear in accordance with the manufacturer's recommendations. The first dose was given on the left side of the animal and the second dose was given on the right side.

For the IC+RAC treatment, the ractopamine feeding period was from 1-wk post-second Improvest® dose (i.e., end of wk 5 of study) to the end of the study period.

Animals and Allotment to Growth Study

A total of 192 pigs that were the progeny of Genetiporc G-Performer sires mated to Genetiporc Fertilis 25 dams (Genetiporc, Alexandria, MN) were used in the study. These were housed in 48 pens of 4 pigs and there were 10 pens of PC, IM, G, and IC and 8 pens of IC+RAC.

At birth, piglets were weighed, and within a litter, male piglets of similar birth weight were randomly assigned to either be physically castrated or left intact (ratio of one male physically castrated to 3 males left intact). Physical castration was carried out at 4 d of age.

Allotment to the growth study was carried out within gender at approximately 15 weeks of age (58.4 ± 2.53 kg BW). Replicates consisted of 5 pens (3 pens of intact males, 1 pen of gilts, and 1 pen of physically-castrated barrows). For the allotment of the intact male pens, pigs were weighed individually and formed into outcome groups of 3 pigs of similar BW, and were randomly allotted from within outcome group to 1 of 3 pens. This process was repeated until there were 4 pigs per pen and the mean pen BW and variation in BW within the 3 pens was similar and representative of the population of intact males available at the time of allotment. Pens were checked to ensure litter mates were allotted to different treatments with pigs being moved to achieve this. Pens were randomly allotted to one of the 3 intact males treatments. For the G and PC treatments, within replicate, pigs that were littermates of the intact males were formed into pens of 4 such that the mean pen BW and variation in BW was representative of the population of each gender available at the time of allotment. After allotment, pigs were allowed a 1-wk acclimation period prior to the start of the growth study.

Animal Housing and Management

From birth to the start of the growth study, pigs were managed according to standard unit protocols. Piglets were born in standard farrowing accommodation and weaned at 20 ± 1 d of age. In the nursery and grower periods, pigs were housed in mixed-gender groups of 6 pigs, and had *ad libitum* access to standard corn-soybean meal-based diets that were formulated to meet or exceed the nutrient requirements of intact males recommended by NRC (1998).

During the study period, pigs were housed in a mechanically ventilated building that had part-solid, part-slotted concrete floors. Pen divisions and gates consisted of vertical steel rods and pen dimensions were 2.59 m × 1.83 m, which provided a floor space of 1.18 m^2/pig. Each pen had a single-space dry-box feeder mounted on the front gate and a nipple-type water drinker. The thermostat was set at 18.5°C throughout the study period and ambient temperature was maintained using thermostatically controlled heaters and fan ventilation.

Diets and Feeding

A 3-phase dietary program (Table 2.1) was used and diets were fed according to a feed budget. The amount fed of the first and second phases were 65.0 and 62.5 kg/pig, respectively; the third phase was fed to the end of the study period. The diets were formulated to meet the nutrient requirements of intact males recommended by NRC (1998). A different diet was used for the third phase for the IC+RAC treatment during the ractopamine feeding period from 1 wk post-second Improvest® dose (i.e., end of wk 5 of study) until the end of the study period and this was formulated to meet or exceed the nutrient requirements of immunologically-castrated barrows fed 5 ppm ractopamine (A. M. Gaines, The Maschhoffs, Carlyle, IL, personal communication). All diets were based on corn and soybean meal and were offered in meal form. Diet formulations and calculated composition of the diets fed during the experimental period are presented in Table 2.1. Pigs had *ad libitum* access to feed and water throughout the study period.

Measurements

Pigs were weighed at the start, and on d 14 and 28 of study, and, subsequently, every wk until the end of the study. Feed additions to the feeders were recorded and feeders were weighed each time pig weights were taken and used to calculate ADFI and G:F.

Statistical Analysis

The PROC UNIVARIATE procedure of SAS (SAS Inst. Inc., Cary, NC) was used to verify normality and homogeneity of variances of the variables. All data conformed to normality assumptions and were analyzed using the PROC MIXED procedure of SAS (Littell et al., 1996). The pen of pigs was the experimental unit for all measurements, and the model used accounted for the fixed effect of treatment and the random effects of block and replicate. Least squares means for the PC, IM, G, and IC treatments were separated using the PDIFF option of SAS with means being considered different at a $P \leq 0.05$. Means for the IC and the IC+RAC treatments were compared using an orthogonal contrast.

RESULTS AND DISCUSSION

Effects of Gender

Least-squares means for the effect of gender on growth performance are presented in Table 2.2. Physically-castrated barrows were heavier ($P \leq 0.05$) at the start of the study compared to the other genders, which had similar ($P > 0.05$) BW. Within replicate, the pigs of the different genders were from the same litters and, therefore, of a similar age at the start of the study. Consequently, gender differences in BW at the start of study are likely to reflect gender differences in pre-test growth rates. However, growth performance prior to the start of test was not measured directly in this study.

For the first 4 wk of the study, between the first and second Improvest® dose, G had lower ($P \leq 0.05$) ADG than the other 3 genders which had similar ($P > 0.05$) growth rates. Physically-castrated barrows had greater ($P \leq 0.05$) ADFI than the other 3 genders which were similar ($P > 0.05$) in this respect. Gain:feed ratio was similar ($P > 0.05$) for IM and IC and was greater ($P \leq 0.05$) for these 2 genders than for PC and G which had similar ($P > 0.05$) feed efficiency. During the period from the second Improvest® dose to slaughter, IC grew faster ($P \leq 0.05$) than the other genders which had similar ($P > 0.05$) growth rates (Table 2.2). In addition, IC had greater ($P < 0.05$) ADFI than IM and G, with PC being intermediate to and different ($P \leq 0.05$) from the other genders for feed intake. Intact males had greater ($P \leq 0.05$) G:F ratio than the other genders; IC had greater ($P \leq 0.05$) feed efficiency than PC, with G being intermediate to and not different ($P > 0.05$) from these 2 genders for feed efficiency (Table 2.2).

For the overall study period (i.e., from first Improvest® dose to end of test), G had similar ($P > 0.05$) ADG and G:F but lower ($P \leq 0.05$) ADFI than PC (Table 2.2). Immunologically-castrated barrows had greater ($P \leq 0.05$) ADG than the other genders, required fewer ($P \leq 0.05$) days to reach slaughter weight, and had greater ($P \leq 0.05$) ADFI than IM and G but not ($P > 0.05$) PC. In addition, overall G:F ratio was greater ($P \leq 0.05$) for IC than PC and G; however, IM that had greater ($P \leq 0.05$) feed efficiency than the other genders (Table 2.2).

The majority of research studies with growing-finishing pigs published in the US over recent years have used physically-castrated barrows and gilts and, consequently, there is limited recently published information on the relative performance of all of the genders that were compared in the current study. In addition, direct comparison of the results of experiments that have evaluated any of these genders with those of the present study is difficult because of differences in the methodology used across studies, particularly as it relates to start and end weights, and the length of the study period.

In the present study, gilts had similar overall growth rate and feed efficiency but lower feed intake than physically-castrated barrows. In agreement with these results, some studies have shown similar growth rates for these 2 genders (Campbell et al., 1989; Morales et al., 2010), however, in other studies, gilts have been shown to grow slower than physically-castrated barrows (Dunshea et al., 2001; Hamilton et al., 2003; Fàbrega et al., 2010). Cisneros et al. (1996) reported similar overall feed efficiency for gilts and physically-castrated barrows, which is similar to the results of the present study. In contrast, however, some studies have reported greater feed efficiency for gilts compared to physically-castrated barrows (Hamilton et al., 2003; Latorre et al., 2004).

The finding that intact males and physically-castrated barrows grew at similar rates in all study periods was somewhat surprising given that a number of previous studies have shown that physically-castrated barrows have generally grown faster than intact males (Zeng et al., 2002; Pauly et al., 2009). However, much of the previous research on the relative performance of intact males and physically-castrated barrows has been carried out to lighter final weights than used in the current study. In addition, the lower feed intake and greater feed efficiency of the intact male compared to the physically-castrated barrow found in the present study is in line with most previous research (Bonneau et al., 1994; Dunshea et al., 2001; Pauly et al., 2009; Fàbrega et al., 2010).

The similar growth performance of intact males and immunologically-castrated barrows in the period between first and second dose was expected given that the immunologically-castrated barrows had received only the first priming dose of Improvest® and would be physiologically similar to the intact male during this period (Millet et al., 2011).

The most relevant practical comparison in relation to the performance of the immunologically-castrated barrow is with the physically-castrated barrow that they would replace if this technology was adopted commercially. There have been a number of studies that have evaluated the growth performance of immunologically- and physically-castrated barrows during the period from the first Improvest® dose to harvest and these have produced variable results. For example, Batorek et al. (2012) carried out a study during this period with individually-housed pigs and found that immunologically-castrated barrows grew faster than physically-castrated barrows, which is similar to the results of the current study. In contrast, a number of studies have reported similar growth rate for these 2 genders during this period (Bonneau et al., 1994; Pauly et al., 2009; Andersson et al., 2012). In these studies, the first Improvest® dose was given at younger ages and lighter weights than in the current study, and, consequently, growth performance was measured over a different weight range and, therefore, and as discussed previously, care must be taken when comparing these results with those of the current study.

In the period before the second Improvest® dose, physically-castrated barrows had greater feed intake and grew at a similar rate to immunologically-castrated barrows. However, from second dose to the end of the study, immunologically-castrated barrows had substantially greater feed intake (14%) and growth rates (23%) than physically-castrated barrows. A number of studies have shown greater feed intake for immunologically- compared to physically-castrated barrows in the period following second Improvest® dose. For example, Fàbrega et al. (2010) found that immunologically-castrated barrows consumed 19% more feed than physically-castrated barrows during this period (86 to 115 kg BW). In contrast, some studies have shown similar feed intake for these 2 genders (Morales et al., 2010; 2011) or a lower feed intake for immunologically-castrated barrows (Bonneau et al., 1994) in the period from the second Improvest® dose to harvest. The reasons for this difference between studies in the relative feed intake of these 2 genders post second dose is not clear and warrants further study. Despite this variation between studies in the difference between physically- and immunologically-castrated barrows for feed intake, the majority of published studies have shown greater growth rates for immunologically- than physically-castrated barrows in the period following the second Improvest® dose, ranging from relatively small (5%; Batorek et al., 2012) to relatively large (>30%; Fàbrega et al., 2010; Schmidt et al., 2011) differences which is in line with the results of the current study.

The growth performance of the 4 genders for each wk of the 4 wk period following second Improvest® dose (i.e., wk 5 to 8 of the study) is presented in Fig. 2.1 to 2.3. For the first wk of these periods, physically-castrated barrows had greater ($P \leq 0.05$) feed intake but similar ($P > 0.05$) growth rate than immunologically-castrated barrows (Fig. 2.1 and 2.2). Subsequent to wk 5, however, feed intake was either similar ($P > 0.05$) for these 2 genders or greater ($P \leq 0.05$) for the immunologically-castrated barrows (Fig. 2.2). In addition, in wk 6, 7, and 8, immunologically-castrated barrows had the highest growth rate of all 4 genders, however, the gender difference was statistically significant ($P \leq 0.05$) for wk 7 only (Fig. 2.1). There was no difference between the genders for G:F ratio in any week following the second dose (Fig. 2.3). These results suggest important changes in feed intake and growth rate of immunologically- compared to physically-castrated barrows from the second week after the second Improvest®

dose onwards that could be of importance under commercial conditions and which warrant further study.

Effects of Feeding Ractopamine to Immunologically-castrated Barrows

Least-squares means for the IC and IC+RAC treatments are presented in Table 2.2 where they have been compared using an orthogonal contrast. These 2 treatments had similar ($P > 0.05$) BW at the start of the study and at the start of the ractopamine feeding period (week 5 of study); however, immunologically-castrated barrows fed 5 compared to 0 ppm ractopamine were 3.6 kg heavier ($P \leq 0.05$) at the end of the study period. In addition, feeding 5 compared to 0 ppm ractopamine to immunologically-castrated barrows increased growth rate (142 g/d; 11.6%; $P \leq 0.05$), and G:F ratio (0.055 kg:kg; 17.3%; $P \leq 0.001$), but had no effect ($P > 0.05$) on ADFI (Table 2.2) during the ractopamine feeding period. Measured over the overall study period, feeding ractopamine at 5 compared to 0 ppm to immunologically-castrated barrows had no effect ($P > 0.05$) on growth rate or feed intake but increased ($P \leq 0.05$) feed efficiency (0.023 kg:kg; 6.2%). Interestingly, the overall feed efficiency for immunologically-castrated barrows fed ractopamine was numerically similar to that for the intact males that were not fed ractopamine (Table 2.2).

Numerous studies have shown that feeding ractopamine to late-finishing pigs increases growth rate and feed efficiency (Uttaro et al., 1993; Armstrong et al., 2004; Patience et al., 2009). Apple et al. (2007) carried out a meta-analysis of published studies that evaluated feeding ractopamine to finishing pigs which showed that, averaged across studies, feeding 5 compared to 0 ppm ractopamine resulted in increases in growth rate and feed efficiency of 12 and 10%, respectively. In the current study, the increase in growth rate of immunologically-castrated barrows from feeding 5 ppm ractopamine was similar to that found by Apple et al. (2007);

however, the improvement in feed efficiency in immunologically-castrated barrows fed ractopamine (17%) was greater than the average of 10% found in the meta-analysis. The majority of the studies included in the meta-analysis of Apple et al. (2007) used physically-castrated barrows and gilts and the current study is one of the first to evaluate the impact of feeding ractopamine to immunologically-castrated barrows. However, some of the studies included in the meta-analysis of Apple et al. (2007) showed responses in feed efficiency to feeding ractopamine at 5 ppm of as great a magnitude as observed in the current study (Stites et al., 1991; Uttaro et al., 1993). Further research is needed to establish if the responses to the feeding of ractopamine are different in immunologically-castrated barrows compared to other genders.

The results of this study, which was carried out in the finishing phase of production, highlighted the growth potential of the immunologically- compared to the physically-castrated barrow, particularly in terms of improved feed efficiency. These results also illustrated the substantial increase in feed efficiency that can be achieved by combining immunological-castration of males using Improvest® with the feeding ractopamine, which, over the study period, amounted to a 17.6% increase in G:F ratio over that of the physically-castrated barrow not fed ractopamine.

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TABLES

Table 2.1. Diet formulations and calculated composition.

	Dietary phase			
	1	2	3	3+RAC[3]
BW range fed, kg:	68-90	90-109	109-130	109-130
Ingredient, %:				
Corn	75.63	78.74	80.44	73.48
Soybean meal	22.53	19.10	17.36	24.69
Limestone	0.68	0.68	0.69	0.67
Monocal 21%	0.41	0.48	0.51	0.38
Salt	0.47	0.46	0.46	0.46
Fat – yellow grease	0.00	0.25	0.25	0.00
L-Lysine	0.15	0.16	0.17	0.15
Alimet	0.02	0.01	0.00	0.03
L-Threonine	0.02	0.03	0.03	0.03
Optiphos 2000	0.01	0.01	0.01	0.01
Trace mineral premix[1]	0.08	0.08	0.08	0.08
Vitamin premix[2]	0.03	0.03	0.03	0.03
Paylean 9[3]	0.00	0.00	0.00	0.03
Calculated composition, %:				
Crude protein	16.41	15.00	14.30	17.30
Crude fat	2.77	3.07	3.11	2.73
Crude fiber	2.23	2.17	2.14	2.26
ADF	3.37	3.32	3.29	3.41
NDF	7.66	7.66	7.66	7.64
Ca	0.45	0.45	0.45	0.45
P, total	0.43	0.43	0.43	0.43
Na	0.20	0.20	0.20	0.20
Lysine, total	0.98	0.89	0.85	1.04
Lysine, digestible	0.86	0.78	0.74	0.91
ME, Kcal/kg	3,308	3,314	3,310	3,312

[1]Provided per kilogram of final diet: iron, 124 mg as iron sulfate; zinc, 124 mg as zinc oxide; manganese, 29 mg as manganese sulfate; copper, 12 mg as copper sulfate; iodine, 0.2 mg as calcium iodate; and selenium, 0.2 mg as sodium selenite.
[2]Provided per kilogram of final diet: vitamin A, 4,410 IU; vitamin D3, 689 IU; vitamin E, 22.1 IU; riboflavin, 4.96 mg; vitamin B12, 0.02 mg; menadione, 1.27 mg; D-pantothenic acid, 17.9 mg; and niacin, 20.9 mg.
[3]RAC = Ractopamine; Paylean 9, Elanco Animal Health, Greenfield, IN; Paylean 9 contains 9.92 mg/kg of ractopamine.

Table 2.2. Least-squares means for the effect of treatment on the growth performance of pigs.

	Treatment[1]						*P* value	
	1	2	3	4	5			
Item	PC	IM	G	IC	IC+RAC[2]	SEM	Treatment	Treatment 4 vs. 5[3]
Number of pens	10	10	10	10	8	-	-	-
BW, kg								
Start of test (first Improvest dose)	69.0[a]	66.5[b]	67.1[b]	66.3[b]	67.4[b]	0.79	0.001	0.09
Week 4 (second Improvest dose)	99.9[a]	98.5[ab]	94.2[c]	97.6[b]	98.6[ab]	1.30	<0.001	0.37
Week 5 (start of ractopamine feeding)	107.1[a]	107.0[a]	101.6[b]	104.9[a]	105.5[a]	1.37	0.001	0.69
End of test (pen mean of 130 kg BW)	131.9[b]	131.7[b]	130.4[b]	132.8[b]	136.4[a]	1.03	0.001	0.01
Days								
Start – End of test	61.6[b]	61.6[b]	66.5[a]	58.1[c]	57.8[c]	1.26	<0.001	0.85
ADG, g/d								
Start – Week 4	1102[a]	1143[a]	968[b]	1121[a]	1106[a]	25.9	<0.001	0.64
Week 4 – End of test	957[b]	1006[b]	942[b]	1179[a]	1282[a]	38.6	<0.001	0.08
Week 5 – End of test	938[c]	950[c]	919[c]	1226[b]	1368[a]	43.6	<0.001	0.03
Start – End of test	1024[bc]	1064[b]	954[c]	1150[a]	1195[a]	25.8	<0.001	0.24
ADFI, kg/d								
Start – Week 4	2.92[a]	2.56[b]	2.53[b]	2.57[b]	2.60[b]	0.064	<0.001	0.63
Week 4 – End of test	3.17[b]	2.80[c]	2.90[c]	3.62[a]	3.45[a]	0.083	<0.001	0.16
Week 5 – End of test	3.15[b]	2.78[c]	2.92[bc]	3.86[a]	3.67[a]	0.093	<0.001	0.17
Start – End of test	3.06[a]	2.68[b]	2.75[b]	3.11[a]	3.04[a]	0.061	<0.001	0.35
G:F, kg/kg								
Start – Week 4	0.377[b]	0.447[a]	0.383[b]	0.436[a]	0.426[a]	0.0072	<0.001	0.33
Week 4 – End of test	0.302[c]	0.358[a]	0.325[bc]	0.326[b]	0.372[a]	0.0089	<0.001	0.001
Week 5 – End of test	0.297[c]	0.340[b]	0.315[c]	0.318[bc]	0.373[a]	0.0092	<0.001	<0.001
Start – End of test	0.335[c]	0.397[a]	0.347[c]	0.371[b]	0.394[a]	0.0068	<0.001	0.02

[a,b,c]For the PC, IM, G, and IC treatments, means within a row with different superscripts are significantly different ($P \leq 0.05$). Superscripts for IC+RAC treatment are compared to IC treatment.

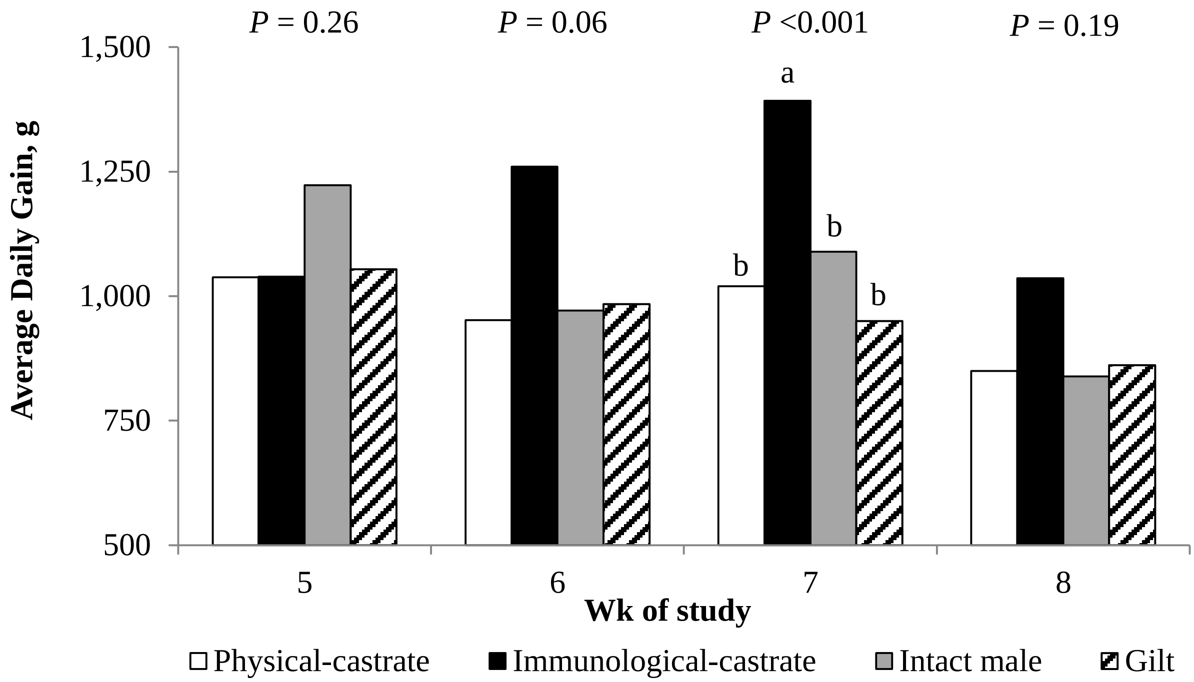
[1]PC = Physically-castrated barrow; IM = Intact male; G = Gilt; IC = Immunologically-castrated barrow; IC+RAC = Immunologically-castrated barrow fed ractopamine.

[2]Ractopamine (Paylean 9, Elanco Animal Health, Greenfield, IN) was included in the diet (at 5 ppm) and fed from week 5 of the study period until end of test.

[3]Means for the IC and IC+RAC treatments were compared using orthogonal contrasts.

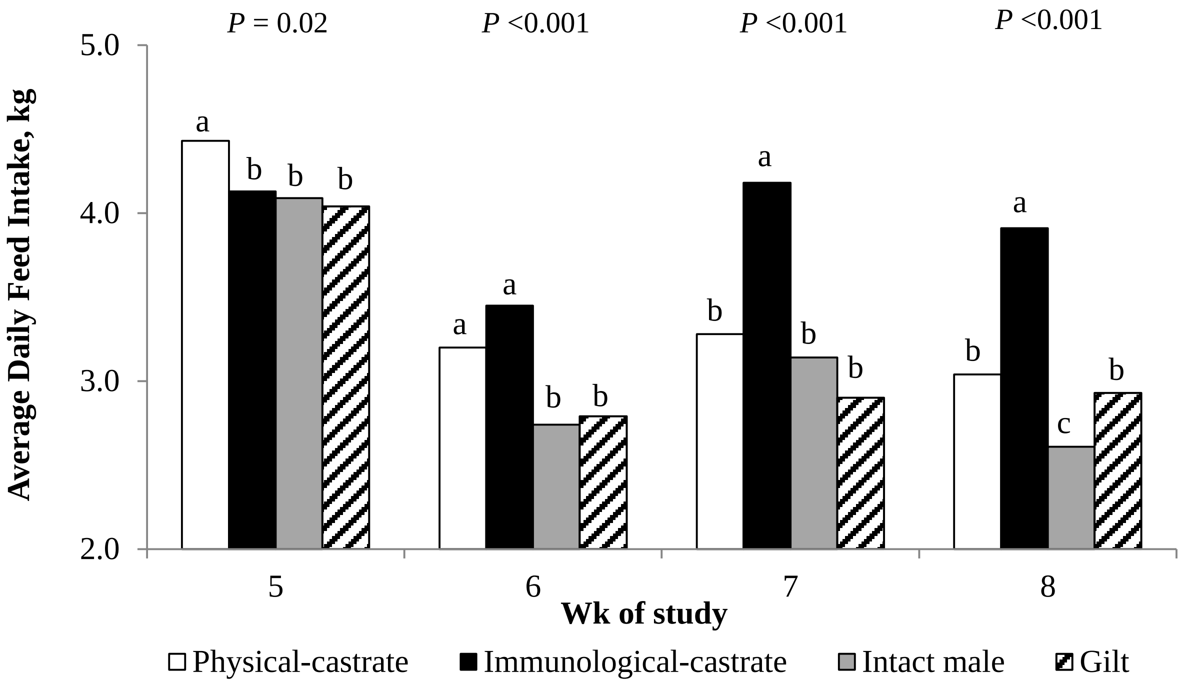
FIGURES

Figure 2.1. Effect of Gender on Weekly ADG Following Second Improvest® Dose.



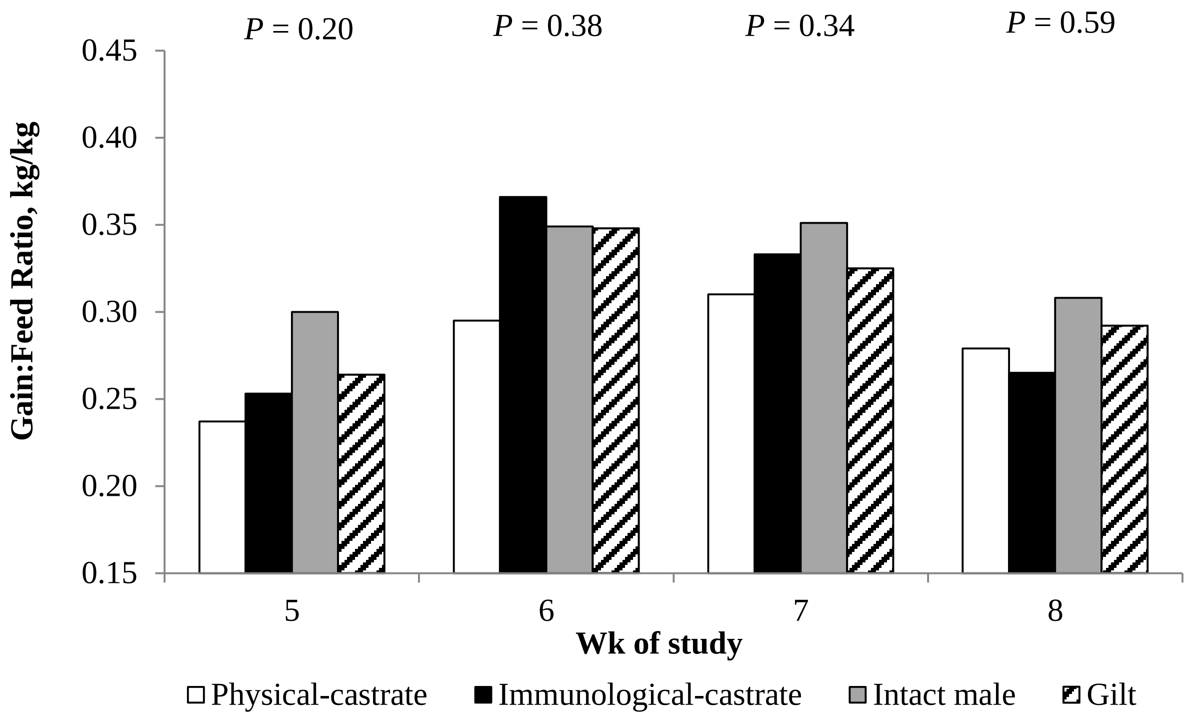
[a,b]Within week, means with different superscripts are different ($P \leq 0.05$).

Figure 2.2. Effect of Gender on Weekly ADFI Following Second Improvest® Dose.



[a,b,c]Within week, means with different superscripts are different ($P \leq 0.05$).

Figure 2.3. Effect of Gender on Weekly G:F Following Second Improvest® Dose.



CHAPTER 3: EFFECTS OF RACTOPAMINE INCLUSION LEVEL ON THE GROWTH PERFORMANCE AND CARCASS CHARACTERISTICS OF IMMUNOLOGICALLY- AND PHYSICALLY-CASTRATED BARROWS AND GILTS.

ABSTRACT

The study was carried out as a randomized complete block design (blocking factor date of start on test) with a 3 × 3 factorial arrangement of treatments: 1) Gender [Physically-castrated barrows (PC), Immunologically-castrated barrows (IC), and Gilts (G)] and 2) Ractopamine (RAC) inclusion level (0, 5, and 7.5 mg/kg). The study used 180 pigs and was carried out from the first Improvest® dose (approximately wk 16 of age; 69.6 ± 2.96 kg BW) for a fixed-time of 61 d. The second Improvest® dose was given 28 d after the first and RAC treatment was applied for the final 26 d of study. Pigs were housed in groups of 4 (5 groups/Gender × RAC subclass) at a floor space of 1.18 m^2/pig. Diets were formulated to meet requirements of intact males for the first 35 d and of intact males fed 7.5 mg/kg RAC for the remainder of the study. Pigs had *ad libitum* access to feed and water throughout the study period. At the end of the study, pigs were harvested at a commercial facility and HCW and backfat thickness was measured. There were no treatment interactions ($P > 0.05$) for any variables. IC had greater ($P \leq 0.05$) overall ADG compared to PC, which grew faster ($P \leq 0.05$) than G (1246, 1083, and 1025 g for IC, PC, and G, respectively; SEM = 20.3). Overall ADFI was lower ($P \leq 0.05$) for G than IC and PC, which had similar ADFI (3.36, 3.37, and 2.87 kg, respectively; SEM = 0.051). Overall G:F was greater ($P \leq 0.05$) for IC than G, and greater for G than PC (0.371, 0.322, and 0.358, respectively; SEM = 0.0039). From d 35 to the end of study, IC had greater ($P \leq 0.05$) ADG (41.5%), ADFI (21.5%), and G:F (16.3%) than PC. Carcass yield was lower ($P \leq 0.05$) for IC compared to PC and G (72.8, 75.0, and 74.6%, respectively; SEM = 0.25). Feeding RAC increased ($P \leq 0.05$) ADG (15.7 and 14.5% for 5 and 7.5 mg/kg, respectively), G:F (17.1 and 16.4%, respectively), carcass

weight (3.7 and 3.2 kg, respectively), and carcass yield (1.0 and 1.0 percentage unit, respectively) compared to the control. The results of this study confirmed previously observed effects of gender and of ractopamine on growth and carcass characteristics and suggest that the response to ractopamine is similar in immunologically- and physically-castrated barrows.

INTRODUCTION

Intact males have improved feed efficiency and carcass leanness compared to physically-castrated barrows (Campbell et al., 1989; Dunshea et al., 2001), but can produce boar taint, the unpleasant odor released when meat from some intact males is cooked (Williams, et al., 1963; Patterson, 1968). Consequently, male pigs are physically castrated to eliminate boar taint. Improvest® (Zoetis, Kalamazoo, MI), a product that immunologically castrates male pigs, is given in 2 doses with the second dose effectively castrating the male. This allows the growth performance of intact males to be exploited for most of the growing period while reducing the risk of boar taint developing. Studies have shown large increases in growth rate and feed intake for immunologically-castrated barrows after the second Improvest® dose but also lower carcass yield for immunologically-castrated barrows compared to other genders (Dunshea et al., 2001; Morales et al., 2013). However, most studies with immunologically-castrated barrows have been carried out to lighter harvest weights than used in the US.

Ractopamine (Paylean, Elanco, Greenfield, IN) is fed in late-finishing to improve growth rate, feed efficiency, and carcass yield and leanness (Apple et al., 2007). In theory, a greater response to ractopamine could be expected in immunologically-castrated barrows than other genders because of this greater feed intake after the second Improvest® dose which coincides with the time of introduction of ractopamine. This may allow producers to minimize the reduction in carcass yield seen in these animals. However, there has been little research evaluating the potential of ractopamine to improve growth and carcass measures in immunologically-castrated barrows at heavy weights. Therefore, the objective of this study was to determine the effects of ractopamine on the growth performance and carcass characteristics of physically-castrated barrows, immunologically-castrated barrows, and gilts.

MATERIALS AND METHODS

The study was conducted at the Swine Research Center of the University of Illinois and the experimental protocol for the study was approved by the University of Illinois Institutional Animal Care and Use Committee.

Experimental Design and Treatments

The study was carried out using a randomized complete block design with a 3 × 3 factorial arrangement of the following treatments: 1) Gender (Physically-castrated barrow, Immunologically-castrated barrow, and Gilt) and 2) Ractopamine Inclusion Level (0, 5, and 7.5 mg/kg). Date of start on the study was used as the blocking factor. The study was carried out over a fixed-time of 61 d from approximately wk 16 of age (69.6 ± 2.96 kg BW) to 136.8 ± 7.32 kg BW.

First and second doses (2 Ml) of Improvest® (Zoetis, Kalamazoo, MI) were given at the start of study and 28 d later, respectively. Improvest® was administered via subcutaneous injection behind and below the base of the ear in accordance with the manufacturer's recommendations. The first dose was given on the left side of the animal and the second dose was given on the right side.

Ractopamine was fed for the final 26 d of the study from 1-wk post-second Improvest® dose (i.e., from d 35 to d 61 of study).

Animals and Allotment to Study

A total of 180 pigs that were the progeny of Genetiporc G-Performer sires mated to Genetiporc Fertilis 25 dams (Genetiporc, Alexandria, MN) were used. These were housed in 45 pens of 4 pigs with 5 pens of each Gender and Ractopamine Inclusion Level treatment combination.

At birth, piglets were weighed and, within a litter, pairs of male piglets of similar birth weight were randomly assigned to be either physically castrated or left intact. Physical castration was carried out at d 4 of age.

Allotment to the growth study was carried out within gender at approximately wk 15 of age (61.9 ± 3.63 kg BW). Replicates consisted of 9 pens (1 pen of each gender on each of the 3 ractopamine inclusion levels). Within gender, pigs were weighed individually, formed into outcome groups of 3 of similar BW, and randomly allotted from within outcome group to 1 of 3 pens. This process was repeated until there were 4 pigs per pen and the mean pen BW and variation in BW within the 3 pens was similar and representative of the population of that gender available at the time of allotment. Pens were checked to ensure litter mates were allotted to different treatments with pigs being moved between pens to achieve this. Within gender, pens were randomly allotted to one of the 3 ractopamine inclusion level treatments. After allotment, pigs were allowed a 7-d acclimation period before the start of the growth study.

Animal Housing and Management

Prior to the start of the growth study, pigs were managed according to standard unit protocols. Sows were farrowed in standard farrowing accommodation and piglets were weaned at 20 ± 1 d. In the nursery and grower periods, pigs were housed in same-gender groups of 6 and 15 pigs, respectively, and had *ad libitum* access to standard corn-soybean meal-based diets that were formulated to meet or exceed the nutrient requirements of intact males recommended by NRC (1998).

During the study period, pigs were housed in a mechanically ventilated building that had part-solid, part-slotted concrete floors. Pen divisions and gates consisted of vertical steel rods and pen dimensions were 2.59 m × 1.83 m, which provided a floor space of 1.18 m^2/pig. Each pen had a single-space dry box feeder mounted on the front gate and a nipple-type water drinker. The thermostat was set at 18.5°C throughout the study period and ambient temperature was maintained using thermostatically controlled heaters and fan ventilation.

Diets and Feeding

A 3-phase dietary program (Table 3.1) was used during the study period. The amount fed of the first dietary phase was 65 kg/pig. The second dietary phase was fed from the end of phase 1 to the start of the ractopamine feeding period, and the third phase was fed to the end of the study period. The diets for the first 2 phases were formulated to meet or exceed the nutrient requirements of intact males recommended by NRC (1998); the third phase was formulated to meet or exceed the nutrient requirements of intact males fed 7.5 mg/kg ractopamine (A. M. Gaines, personal communication). All diets were based on corn and soybean meal and were offered in meal form. Diet formulations and calculated composition of the diets fed during the experimental period are presented in Table 3.1. Pigs had *ad libitum* access to feed and water throughout the study period.

Growth Study Measurements

Pigs were weighed at the start, and on d 14 and 28 of study, and, subsequently, every week until the end of the study. Feed additions to the feeders were recorded and feeders were weighed each time pig weights were taken and used to calculate ADFI and G:F.

Harvest and Carcass Measurements

At the completion of the study (i.e., d 61), all pigs were individually weighed and tattooed with a unique identification number and transported to a commercial slaughter facility, a journey of 960 km that took approximately 10 h. Pigs were unloaded and held in lairage for approximately 3 h with access to water, but not feed. Harvest was carried out using standard procedures, and HCW was taken immediately after carcass dressing. Backfat thickness was collected on the midline at the last rib on the slaughter line by plant personnel using a stainless steel ruler. Measurements for backfat thickness were not recorded but values were used to assign carcass grade using the following scale: 1 = equal to or less than 1.00 cm; 2 = 1.01 – 1.50 cm; 3 = 1.51 – 2.00 cm; 4 = 2.01 – 2.50 cm; 5 = 2.51 – 3.00 cm; 6 = equal to or greater than 3.00 cm.

Statistical Analysis

The PROC UNIVARIATE procedure of SAS (SAS Inst. Inc., Cary, NC) was used to verify normality and homogeneity of variances of the variables. All variables that conformed to normality assumptions were analyzed using the PROC MIXED procedure of SAS (Littell et al., 1996). The pen of pigs was the experimental unit for all measurements, and the model used accounted for the fixed effects of Gender, Ractopamine Inclusion Level, and the Gender by Ractopamine Inclusion Level treatment interaction and the random effects of block and replicate. Least-squares means were separated using the PDIFF option of SAS with means being considered different at a $P \leq 0.05$.

RESULTS AND DISCUSSION

Least-squares means for the effects of Gender and Ractopamine inclusion level on growth performance and carcass characteristics are summarized in Table 3.2 and 3.3, respectively. There were no Gender by Ractopamine level interactions for any of the measured variables, suggesting that the response to ractopamine was similar for all the genders, which is similar to the results of a number of previous studies (Moore et al., 2009; Rikard-Bell et al., 2009; Rocha et al., 2013).

Gender Effects

Growth Performance. Physically-castrated barrows were heavier ($P \leq 0.05$) at the start of test compared to immunologically-castrated barrows, which were heavier ($P \leq 0.05$) than gilts. These results are similar to those of Puls et al. (2013) that showed that physically-castrated barrows were heavier than immunologically-castrated barrows and gilts at approximately wk 16 of age. In the current study and that of Puls et al. (2013), the pigs of the 3 genders were from the same litters and, therefore, of a similar age at the start of test, and, consequently, gender differences in BW at the start of study are likely to reflect differences in pre-test growth rates. However, growth performance prior to the start of test was not measured directly in this study.

Compared to physically-castrated barrows, gilts had lower ($P \leq 0.05$) overall ADG, lower ($P \leq 0.05$) ADFI, but greater ($P \leq 0.05$) G:F (Table 3.2). These results are generally in line with previous research. For example, Hamilton et al. (2003) and Latorre et al. (2004) showed that gilts grew slower, and had lower feed intake, but greater feed efficiency compared to physically-castrated barrows.

For the overall study period (i.e., first Improvest® dose to slaughter), immunologically-castrated barrows had greater (15.1%; $P \leq 0.05$) ADG compared to physically-castrated barrows, which resulted in greater ($P \leq 0.05$) live weight at the end of test (Table 3.2). Overall ADFI for immunologically-castrated barrows and physically-castrated barrows was similar ($P > 0.05$); however, immunologically-castrated barrows had greater (15.2%; $P \leq 0.05$) overall G:F compared to physically-castrated barrows.

There have been a relatively limited number of studies involving immunologically-castrated barrows carried out to heavier harvest weights such as those used in the current study, which makes comparison of the results from this study and others difficult. However, in contrast to the results of the present study, some studies have reported no difference in growth rate from the first Improvest® dose to harvest weights for physically- and immunologically-castrated barrows (Fàbrega et al., 2010; Font-i-Furnols et al., 2012, Morales et al., 2013). Many of these studies, however, gave the first Improvest® dose much earlier and at lighter weights than in the current study, which could explain differences in results between these studies and the present experiment. In agreement with the current study, most studies have reported that immunologically-castrated barrows had similar feed intake (Zamaratskaia et al., 2008; Fàbrega et al., 2010) and greater feed efficiency (Dunshea et al., 2001; Pauly et al., 2009; Fàbrega et al., 2010) than physically-castrated barrows in the period from first Improvest® dose to harvest.

The ranking of the genders for growth performance changed in the period before compared to the period after the second Improvest® dose. For the first 28 d of study (i.e., from first to second Improvest® dose), immunologically-castrated barrows had similar ($P > 0.05$) ADG than physically-castrated barrows, but had lower (18.4%; $P \leq 0.05$) ADFI and greater (22.9%; $P \leq 0.05$) G:F (Table 3.2). After second Improvest® dose, however, immunologically-castrated barrows grew faster (28.6%; $P \leq 0.05$), consumed more feed (12.3%; $P \leq 0.05$), and had greater feed efficiency (14.3%; $P \leq 0.05$) than physically-castrated barrows (Table 3.2). In the period before the second Improvest® dose, immunologically-castrated barrows are physiologically the same as intact males (Millet et al., 2011) and, therefore, their growth performance should be similar to this gender; generally, intact males have been shown to have lower feed intake but greater feed efficiency than physically-castrated barrows (Bonneau et al., 1994; Fàbrega et al., 2010, Morales et al., 2010). In addition, the growth performance of immunologically-castrated barrows has been shown to greatly increase relative to that of other genders following the second Improvest® dose (Dunshea et al., 2001; Fàbrega et al., 2010; Morales et al., 2013), which is consistent with the results of the current study.

To provide more detail of the changes in relative growth of the genders after the second Improvest® dose, the results for each 7-d period (with the exception of the last period which was 5 d) are presented in Fig. 3.1 to 3.3. In the first 7 d following second Improvest® dose (i.e., d 28-35 of study), physically-castrated barrows grew at a similar rate to immunologically-castrated barrows (Fig. 3.1). In each of the subsequent weeks, however, immunologically-castrated barrows grew faster ($P \leq 0.05$) than physically-castrated barrows, and for the final 26 d of the study period had 41.5% greater growth rate (Fig. 3.1). Feed intake was greater ($P \leq 0.05$) for physically-castrated barrows in the first 7 d following second Improvest® dose (Fig. 3.2); subsequently, however, feed intake was greater for immunologically-castrated barrows than physically-castrated barrows in every period to the end of the study and was 21.5% greater ($P \leq 0.05$) for the final 26 d of the study period (Fig. 3.2). There were limited differences between the genders for feed efficiency in the period following second Improvest® dose (Fig. 3.3). Immunologically-castrated barrows and gilts had greater ($P \leq 0.05$) feed efficiency than physically-castrated barrows from days 35 to 42 and for the overall period post-second dose (d 28 to 61). For the other periods, feed efficiency of immunologically-castrated barrows and gilts was generally greater than for physically-castrated barrows but the difference between the genders was not significant ($P > 0.05$).

Carcass Characteristics. Compared to physically-castrated barrows, gilts had lower ($P \leq 0.05$) final farm weight and carcass weight but similar ($P > 0.05$) carcass yield. The differences reported in the literature for carcass yield between physically-castrated barrows and gilts are inconsistent. For example, some studies have shown carcass yield to be greater for physically-castrated barrows compared to gilts (Fàbrega et al., 2010), others have reported no difference between the genders for carcass yield (Cisneros et al., 1996; Gispert et al., 2010, Morales et al., 2010), and some studies have shown a greater carcass yield for gilts compared to physically-castrated barrows (Ellis et al., 1996; Latorre et al., 2004; Morales et al., 2013). Additionally, gilts had lower ($P \leq 0.05$) backfat thickness compared to physically-castrated barrows (Table 3.3), results that are generally in line with previous research (Fàbrega et al., 2010; Morales et al., 2010; Font-i-Furnols et al., 2012).

Immunologically-castrated barrows had greater ($P \leq 0.05$) final farm live weight but similar ($P > 0.05$) HCW than physically-castrated barrows, which resulted in a 2.2 percentage unit disadvantage for carcass yield for immunologically-castrated barrows. Previous studies have generally shown a lower carcass yield for immunologically-castrated barrows compared to physically-castrated barrows (Dunshea et al., 2001; Fàbrega et al., 2010; Morales et al., 2013), with the difference between the 2 genders ranging from as little as 0.4 percentage units (Zeng et al., 2002) to as great as 3.9 percentage units (Fàbrega et al., 2010). Boler et al. (submitted, 2013) reported that, compared to physically-castrated barrows, immunologically-castrated barrows had a 1.5 percentage unit lower carcass yield, and that this difference resulted from increased weights of gut fill, testicles, reproductive tract, kidney, and liver.

There was no difference ($P > 0.05$) in backfat thickness between immunologically-castrated and physically-castrated barrows, results consistent with a number of other studies (D'Souza and Mullan, 2003; Fàbrega et al., 2010; Morales et al., 2010). However, there are reports of lower backfat thickness for immunologically-castrated barrows compared to physically-castrated barrows (Dunshea et al., 2001; Morales et al., 2011; Morales et al., 2013). This difference could be related to variation between studies in factors such as harvest weights and the timing of harvest relative to the time of second Improvest® dose.

Ractopamine Inclusion Level Effects

Growth Performance. There was no difference (*P* > 0.05) between the ractopamine inclusion levels for BW at any time during the study period (Table 3.2). During the ractopamine feeding period (i.e., d 35 to d 61 of study), pigs fed either 5 or 7.5 mg/kg RAC compared to the control (0 mg/kg) grew faster (15.7% and 14.5% for 5 and 7.5 mg/kg, respectively; $P \leq 0.05$) and had greater feed efficiency (17.1% and 16.4%, respectively; $P \leq 0.05$), results which are consistent with previous research (Patience et al., 2009; Hinson et al., 2011). The extent of increases in growth rate and feed efficiency are within the range reported in a meta-analysis by Apple et al. (2007), that showed feeding 5 and 10 mg/kg ractopamine was associated with increases in growth rate of, on average, 12.0 and 11.8%, respectively, and in feed efficiency of 10.0 and 13.3%, respectively. Similar to the results of other studies (Patience et al., 2009; Hinson et al., 2011), there were no effect (*P* > 0.05) of ractopamine inclusion level on feed intake (Table 3.2).

Carcass Characteristics. Feeding ractopamine (at 5 or 7.5 mg/kg) compared to the control (0 mg/kg) increased ($P \leq 0.05$) carcass weight and carcass yield (Table 3.3). The increase in yield, which was 1.0 percentage unit for both ractopamine inclusion levels, is greater than that suggested by the meta-analysis of Apple et al. (2007), which reported a 0.2 to 0.6 percentage unit improvement for pigs fed 5 and 10 mg/kg RAC, respectively. In the present study, there was no effect (*P* > 0.05) of ractopamine inclusion level on backfat thickness (Table 3.3). Previous research has reported that compared to 0 mg/kg, feeding 5 or 10 mg/kg ractopamine had either no effect (Stites et al., 1991; Armstrong et al., 2004) or reduced backfat thickness (Uttaro et al., 1993; Patience et al., 2009). In addition, Apple et al. (2007) reported that feeding 5 or 10 mg/kg reduced backfat thickness by 0.04 and 0.14 cm, respectively. The lack of response to feeding ractopamine in backfat thickness observed in the current study could be related to the method of measurement where a carcass grade rather than an actual backfat thickness was given.

The results of this study confirm previously observed gender differences in growth performance and carcass measures and show that immunological castration of intact male pigs can increase growth rate and feed intake in late finishing. However, the reduction in carcass yield for immunologically-castrated barrows relative to the other genders is of concern and warrants further research. In addition, feeding ractopamine at 5 or 7.5 mg/kg increased growth rate, feed efficiency, and carcass yield. Finally, the lack of a Gender × Ractopamine inclusion level interaction for any growth performance and carcass measures suggests that the response to ractopamine was similar across genders, and that the growth performance responses to immunological castration with Improvest® and to ractopamine are likely to be additive.

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TABLES

Table 3.1. Diet formulations and calculated composition.

	Dietary phase		
	1	2	3[1]
Approximate BW range fed, kg:	68-90	90-109	109-135
Ingredient, %			
Yellow corn	75.63	78.74	71.02
Soybean meal	22.53	19.10	27.20
Limestone	0.68	0.68	0.68
Monocal 21%	0.41	0.48	0.29
Salt	0.47	0.46	0.46
Fat - yellow grease	0.00	0.25	0.00
L-Lysine	0.15	0.16	0.15
Alimet	0.02	0.01	0.05
L-Threonine	0.02	0.03	0.05
Optiphos 2000	0.01	0.01	0.01
Trace mineral premix[2]	0.08	0.08	0.08
Vitamin premix[3]	0.03	0.03	0.03
Calculated composition, %			
Crude protein	16.16	14.73	18.14
Crude fat	2.80	3.09	2.71
Crude fiber	1.99	1.93	2.08
ADF	3.02	2.92	3.15
NDF	7.78	7.76	7.77
Ca	0.46	0.46	0.45
P, total	0.44	0.44	0.43
Na	0.20	0.20	0.20
Lysine, total	0.98	0.89	1.11
Lysine, digestible	0.86	0.78	0.98
ME, Kcal/kg	3,308	3,314	3,319

[1]Ractopamine (Paylean 9, Elanco Animal Health, Greenfield, IN; Paylean 9 contained 9.92 mg/kg of ractopamine) was included in dietary phase 3 at the expense of corn to form final diets containing either 5 or 7.5 mg/kg ractopamine.
[2]Provided per kg of final diet: iron, 124 mg as iron sulfate; zinc, 124 mg as zinc oxide; manganese, 29 mg as manganese sulfate; copper, 12 mg as copper sulfate; iodine, 0.2 mg as calcium iodate; and selenium, 0.2 mg as sodium selenite.
[3]Provided per kg of final diet: vitamin A, 4,410 IU; vitamin D3, 689 IU; vitamin E, 22.1 IU; riboflavin, 4.96 mg; vitamin B12, 0.02 mg; menadione, 1.27 mg; D-pantothenic acid, 17.9 mg; and niacin, 20.9 mg.

Table 3.2. Least-squares means for the effects of Gender and Ractopamine (RAC) Inclusion Level on the growth performance of pigs.

	Gender[1]				RAC inclusion level, mg/kg[2]				*P*-value		
Item	PC	IC	G	SEM	0	5	7.5	SEM	Gender	RAC[2]	Gender × RAC[2]
Number of pens	15	15	15	-	15	15	15	-	-	-	-
BW, kg											
Start of test (first Improvest® dose)	72.6^{a}	69.0^{b}	67.3^{c}	0.69	69.7	69.7	69.5	0.69	<0.001	0.98	0.92
Day 28 (second Improvest® dose)	102.6^{a}	98.6^{b}	95.0^{c}	0.86	99.7	98.5	98.1	0.86	<0.001	0.32	0.99
Day 35 (start of ractopamine feeding)	110.9^{a}	105.8^{b}	101.9^{c}	1.13	107.2	105.5	105.9	1.13	<0.001	0.37	1.00
End of test (day 61; harvest)	137.4^{b}	143.1^{a}	129.8^{c}	1.30	134.9	138.0	137.4	1.30	<0.001	0.22	0.94
ADG, g											
Start – Day 28	1073^{a}	1068^{a}	991^{b}	20.4	1074	1040	1018	20.4	0.01	0.17	0.77
Day 28 – End of test	1071^{b}	1377^{a}	1053^{b}	24.6	1084^{b}	1200^{a}	1218^{a}	24.6	<0.001	0.001	0.92
Day 35 – End of test	1034^{b}	1463^{a}	1075^{b}	26.2	1082^{b}	1252^{a}	1239^{a}	26.2	<0.001	<0.001	0.80
Start – End of test	1083^{b}	1246^{a}	1025^{c}	20.3	1090	1126	1137	20.3	<0.001	0.24	0.55
ADFI, kg											
Start – Day 28	2.93^{a}	2.39^{b}	2.35^{b}	0.106	2.58	2.52	2.57	0.106	<0.001	0.68	0.91
Day 28 – End of test	3.50^{b}	3.93^{a}	3.10^{c}	0.056	3.56	3.49	3.48	0.056	<0.001	0.51	0.24
Day 35 – End of test	3.44^{b}	4.18^{a}	3.13^{c}	0.058	3.61	3.59	3.56	0.058	<0.001	0.78	0.48
Start – End of test	3.37^{a}	3.36^{a}	2.87^{b}	0.051	3.24	3.16	3.20	0.051	<0.001	0.56	0.28
G:F, kg:kg											
Start – Day 28	0.367^{c}	0.451^{a}	0.427^{b}	0.0171	0.421	0.420	0.404	0.0171	<0.001	0.16	0.42
Day 28 – End of test	0.307^{b}	0.351^{a}	0.340^{a}	0.0047	0.304^{b}	0.344^{a}	0.349^{a}	0.0047	<0.001	<0.001	0.37
Day 35 – End of test	0.301^{b}	0.350^{a}	0.343^{a}	0.0064	0.298^{b}	0.349^{a}	0.347^{a}	0.0064	<0.001	<0.001	0.51
Start – End of test	0.322^{c}	0.371^{a}	0.358^{b}	0.0039	0.337^{b}	0.357^{a}	0.356^{a}	0.0039	<0.001	<0.001	0.76

[a,b,c]Means within a row with different superscripts are different ($P \leq 0.05$).

[1]PC = Physically-castrated barrow; IC = Immunologically-castrated barrow; G = Gilt.

[2]Ractopamine (Paylean 9, Elanco Animal Health, Greenfield, IN) was included in the diet fed from d 35 until the end of the study period.

Table 3.3. Least-squares means for the effects of Gender and Ractopamine (RAC) inclusion level on carcass characteristics of pigs.

	Gender[1]				RAC inclusion level, mg/kg[2]				*P*-value		
Item	PC	IC	G	SEM	0	5	7.5	SEM	Gender	RAC[2]	Gender × RAC[2]
Number of pens	15	15	15	-	15	15	15	-	-	-	-
Final farm live weight, kg	137.4[b]	143.1[a]	129.8[c]	1.30	134.9	138.0	137.4	1.30	<0.001	0.22	0.94
Hot carcass weight, kg	103.1[a]	104.2[a]	96.8[b]	1.08	99.1[b]	102.8[a]	102.3[a]	1.08	<0.001	0.03	0.96
Carcass yield, %	75.0[a]	72.8[b]	74.6[a]	0.25	73.5[b]	74.5[a]	74.5[a]	0.25	<0.001	0.002	0.36
Carcass grade[3]	3.43[a]	3.19[a]	2.80[b]	0.19	3.25	3.03	3.14	0.19	0.002	0.40	0.13

[a,b,c]Means within a row with different superscripts are different ($P \leq 0.05$).

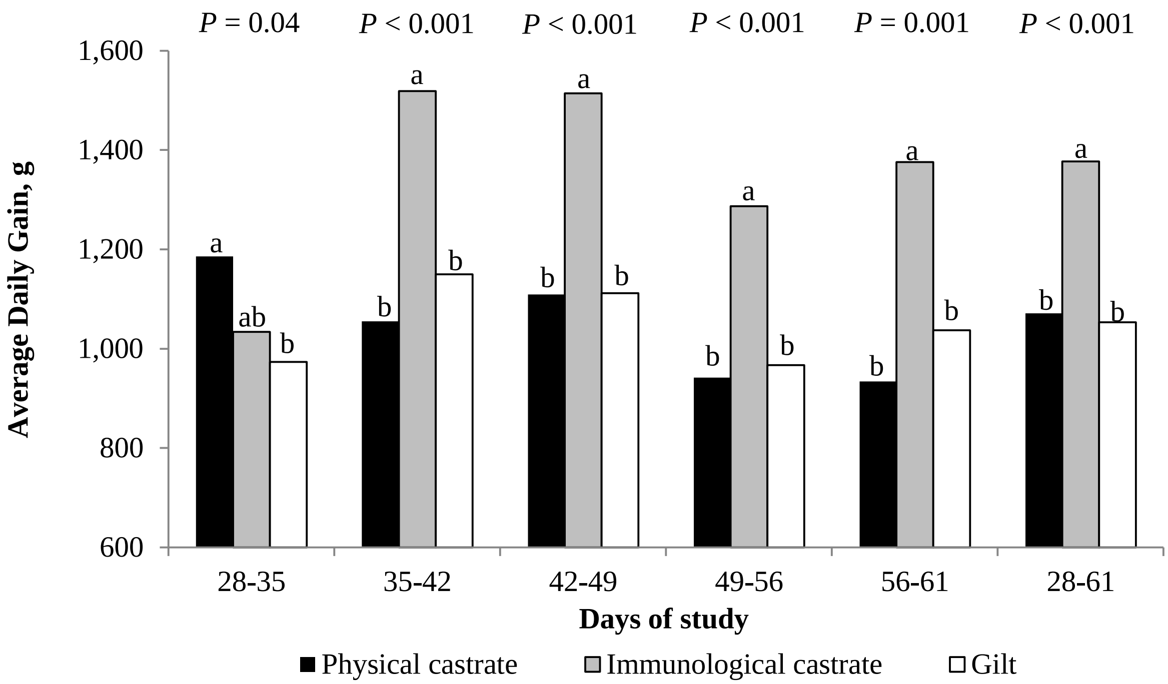
[1]PC = Physically-castrated barrow; IC = Immunologically-castrated barrow; G = Gilt.

[2]Ractopamine (Paylean 9, Elanco Animal Health, Greenfield, IN) was included in the diet fed from d 35 until the end of the study period.

[3]Carcass grade determined on last rib backfat thickness: 1 = equal to or less than 1.00 cm; 2 = 1.01 – 1.50 cm; 3 = 1.51 – 2.00 cm; 4 = 2.01 – 2.50 cm;

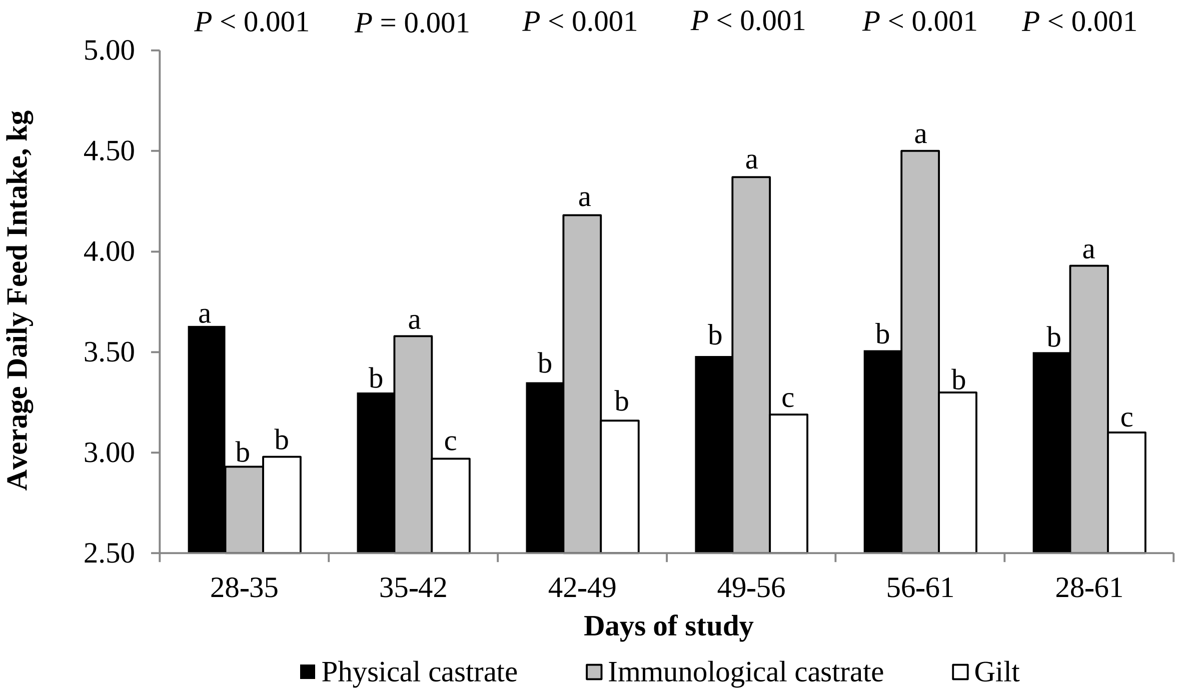
FIGURES

Figure 3.1. Effect of Gender on Weekly Average Daily Gain Following Second Improvest® Dose.



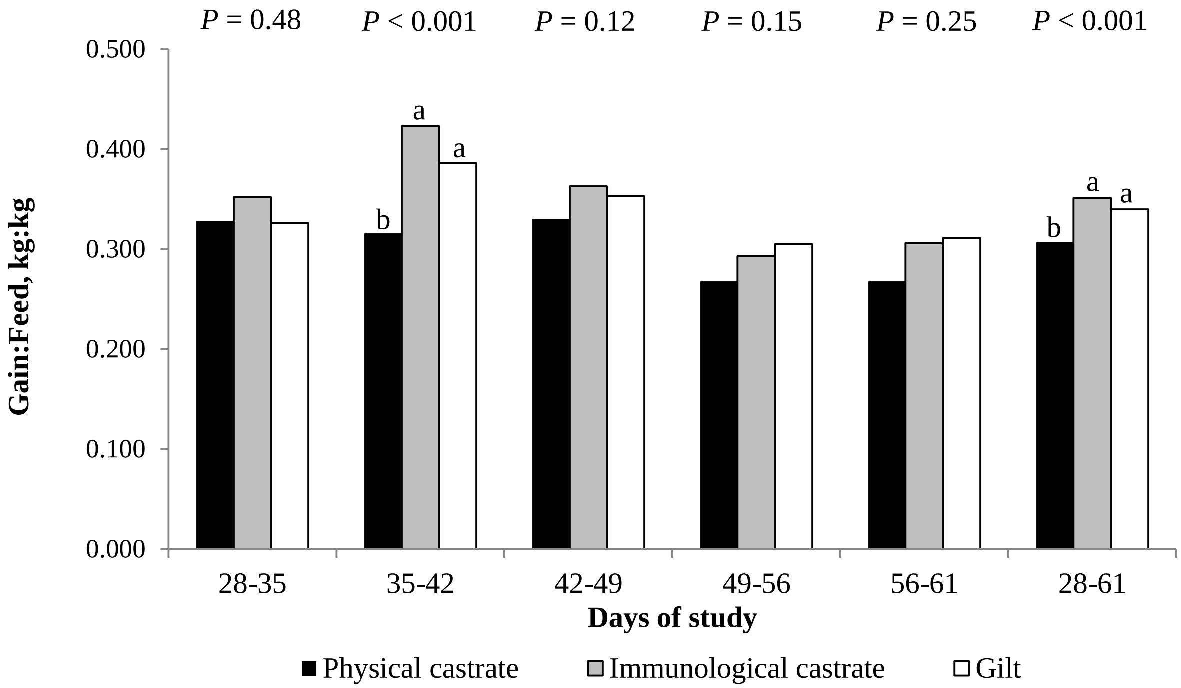
[a,b]Within days of study, means with different superscripts are different ($P \leq 0.05$).

Figure 3.2. Effect of Gender on Weekly Average Daily Feed Intake Following Second Improvest® Dose.



[a,b,c]Within days of study, means with different superscripts are different ($P \leq 0.05$).

Figure 3.3. Effect of Gender on Weekly Gain:Feed Ratio Following Second Improvest® Dose.



[a,b]Within days of study, means with different superscripts are different ($P \leq 0.05$).

CHAPTER 4: EFFECTS OF TIMING OF SECOND IMPROVEST® DOSE RELATIVE TO END OF TEST ON THE GROWTH PERFORMANCE OF IMMUNOLOGICALLY-CASTRATED BARROWS IN COMPARISON TO PHYSICALLY-CASTRATED BARROWS AND GILTS.

ABSTRACT

This study was carried out to evaluate the effects of timing of second Improvest® dose and age at end of test relative to the time of second Improvest® dose on the growth performance and carcass characteristics of immunologically-castrated barrows (IC) in comparison to physically-castrated barrows (PC) and gilts (G). The study was carried out as a RCBD with 12 treatments: 1 to 4) IC given second Improvest® dose at wk 14, 16, 18, and 20 of age, respectively; end of test = wk 24 of age, 5) IC given second dose at wk 20 of age; end of test = wk 26 of age, 6) IC given second Improvest® dose at wk 20 of age; end of test = wk 28 of age, 7 to 9) PC; end of test = wk 24, 26, and 28 of age, respectively, and 10 to 12) G; end of test = wk 24, 26, and 28 of age, respectively. A total of 288 pigs (initial BW 29.3 ± 3.30 kg; approximately 9 wk of age) were housed in groups of 3 (8 groups/treatment). Diets were formulated to meet requirements of intact males throughout the study period; pigs had *ad libitum* access to feed and water. Pigs were sent to a commercial facility for harvest where HCW and backfat thickness was measured. G had lower ($P \leq 0.05$) ADG, lower ($P \leq 0.05$) ADFI, and greater ($P \leq 0.05$) G:F than the other genders. IC had greater ($P \leq 0.05$) ADG and G:F, but similar ($P > 0.05$) ADFI, than PC. Overall ADFI was greater ($P \leq 0.05$), and G:F was lower ($P \leq 0.05$), for IC given Improvest® early (i.e., wk 14 or 16 of age) compared to late (i.e., wk 18 or 20 of age) in the growth period, and were more similar to PC. Carcass yield and backfat thickness were generally similar for G and PC. Carcass yield was numerically higher ($P > 0.05$) for IC given second Improvest® dose early in the growth period compared to late, but was lower ($P \leq$

0.05) than PC for all treatments involving IC. In general, these results support the concept that increasing time between second Improvest® dose and end of test lowers overall growth performance. Furthermore, these results suggest that there is no advantage in growth performance, and relatively modest improvements in carcass yield, from giving second Improvest® dose earlier than 4-wk prior to harvest.

INTRODUCTION

It has been well documented that intact males have greater feed efficiency and improved carcass leanness compared to physically-castrated barrows (Dunshea et al., 2001; Pauly et al., 2009; Puls et al., 2013a). However, intact males can produce pork with a high incidence of boar taint, the unpleasant odor released when meat from some intact males is cooked (Williams, et al., 1963; Patterson, 1968). For this reason, most male pigs are physically castrated early in life, typically within the first 7 d of age. Improvest® (Zoetis, Kalamazoo, MI) is a product that immunologically castrates male pigs and has been approved for use in a number of countries including the US. The product is given in 2 doses with the second dose, which is generally given in late finishing, effectively castrating the male. Using Improvest® allows producers to exploit the growth performance advantages of the intact male early in the growth period while greatly reducing the risk of boar taint from developing later. The product label states that animals must be sent for harvest 3 to 10 weeks after being given the second dose. However, most research with immunological castrates has ended 4-wk after the second dose, and has shown that immunological castrates tend to have lighter and thinner bellies than physical castrates (Pauly et al., 2009; Boler et al., 2011; Boler et al., 2012). In practice, pigs will be sent for harvest over a range of ages and weeks post-second Improvest® dose. Still, little is known about the growth performance and carcass characteristics of immunological castrates over a range of time post-second Improvest® dose.

Therefore, the objective of this research was to evaluate the effects of time from second Improvest® dose and age at end of test relative to the time of second Improvest® dose on the growth performance and carcass characteristics of immunologically-castrated barrows in comparison to physically-castrated barrows and gilts.

MATERIALS AND METHODS

The study was conducted at the Swine Research Center of the University of Illinois and the experimental protocol for the study was approved by the University of Illinois Institutional Animal Care and Use Committee.

Experimental Design and Treatments

The study was carried out using a randomized complete block design with the following 12 treatments:

Treatment	Gender	Time of 2nd Improvest® Dose	Time at End of Test	Time after Second Dose
1	Immunological castrate	wk 14 of age	wk 24 of age	10 weeks
2	Immunological castrate	wk 16 of age	wk 24 of age	8 weeks
3	Immunological castrate	wk 18 of age	wk 24 of age	6 weeks
4	Immunological castrate	wk 20 of age	wk 24 of age	4 weeks
5	Immunological castrate	wk 20 of age	wk 26 of age	6 weeks
6	Immunological castrate	wk 20 of age	wk 28 of age	8 weeks
7	Physical castrate	-	wk 24 of age	-
8	Physical castrate	-	wk 26 of age	-
9	Physical castrate	-	wk 28 of age	-
10	Gilt	-	wk 24 of age	-
11	Gilt	-	wk 26 of age	-
12	Gilt	-	wk 28 of age	-

Date of start on the study was used as the blocking factor. The study was carried out from approximately wk 9 of age (29.3 ± 3.30 kg BW) to either wk 24, 26, or 28 of age, depending on treatment.

First and second doses (2 mL) of Improvest® (Zoetis, Kalamazoo, MI) were given at the start of study (wk 9 of age) and at either wk 14, 16, 18, or 20 of age, depending on treatment. Improvest® was administered via subcutaneous injection behind and below the base of the ear in accordance with the manufacturer's recommendations.

Animals and Allotment to Study

A total of 288 pigs that were progeny of Genetiporc G-Performer sires mated to Genetiporc Fertilis 25 dams (Genetiporc, Alexandria, MN) were used. Replicates consisted of 12 single-gender pens (6 pens of immunologically-castrated barrows, 3 pens of physically-castrated barrows, and 3 pens of gilts) of 3 pigs.

At birth, piglets were weighed and, within a litter, male piglets of similar birth weight were randomly assigned to either be physically castrated or left intact (ratio of 1:2). Physical castration of pigs was carried out at d 4 of age.

Allotment to the growth study was carried out within gender at approximately wk 9 of age. For immunologically-castrated barrows, pigs were weighed individually and formed into outcome groups of 6 pigs of similar BW, and were randomly allotted from within outcome group to pens. This process was repeated until there were 3 pigs per pen and the mean pen BW and variation in BW within the pens was similar and representative of the population of that gender available at the time of allotment. Pens were checked to ensure litter mates were allotted to different treatments with pigs being moved between pens to achieve this. For physically-castrated barrows and gilts, litter mates of the immunologically-castrated barrows were selected and formed into outcome groups of 3, and allotted to study following the same procedure as described above. Within gender, pens were randomly age at end of test treatment. Following allotment, pigs were moved to their allotted pen and location within the facility, and immediately started the growth study.

Animal Housing and Management

Prior to the start of the growth study, pigs were managed according to standard unit protocols. Sows were farrowed in standard farrowing accommodation and piglets were weaned at 20 ± 1 d. In the nursery period, pigs were housed in same-gender groups of 6 pigs, respectively, and had *ad libitum* access to standard corn-soybean meal-based diets that were formulated to meet or exceed the nutrient requirements of intact males recommended by NRC (2012).

Pigs were moved to the experimental facility at approximately wk 9 of age. During the study period, pigs were housed in a mechanically ventilated building that had part-solid, part-slotted concrete floors. Each pen had a single-space dry box feeder mounted on the front gate and a nipple-type water drinker. Pen divisions and gates consisted of vertical steel rods. Pen dimensions were 1.37 × 2.34 m, which provided a usable floor space of 0.94 m^2/pig. The thermostat was set at 18.5°C throughout the study period and ambient temperature was maintained using thermostatically controlled heaters and fan ventilation.

Diets and Feeding

A 5-phase dietary program (Table 4.1) was used during the study period. Diets were fed according to the following feed budget: Phase 1 = 40.0 kg/pig; Phase 2 = 52.3 kg/pig; Phase 3 = 63.3 kg/pig; Phase 4 = 56.7 kg/pig; Phase 5 = fed from the end of phase 4 to the end of the study. Diets were formulated to meet or exceed the nutrient requirements of intact males recommended by NRC (2012). All diets were based on corn and soybean meal and were offered in meal form. Diet formulations and calculated composition of the diets fed during the experimental period are presented in Table 4.1. Pigs had *ad libitum* access to feed and water throughout the study period.

Growth Study Measurements

All pigs were weighed at the start (wk 9 of age), and wk 2 and 4 of study, and subsequently, every week until the end of the study. Feed additions to the feeders were recorded and feeders were weighed each time pig weights were taken and used to calculate ADFI and G:F.

Harvest and Carcass Measurements

At the completion of the growth study, all pigs were individually weighed and tattooed with a unique identification number and transported to a commercial slaughter facility, a journey of 310 km that took approximately 3 h. Pigs were unloaded and held in lairage for approximately 10 h with access to water, but not feed. Pigs were harvested using standard procedures, HCW was measured immediately after carcass dressing, and backfat thickness was measured on the midline at the last rib using a stainless steel ruler.

Statistical Analysis

The PROC UNIVARIATE procedure of SAS (SAS Inst. Inc., Cary, NC) was used to verify normality and homogeneity of variances of the variables. All variables conformed to normality assumptions and were analyzed using the PROC MIXED procedure of SAS (Littell et al., 1996). The pen of pigs was the experimental unit for all measurements. The model that was used accounted for the fixed effect of treatment and the random effects of block and replicate. Least-squares means were separated using the PDIFF option of SAS with means being considered different at a $P \leq 0.05$.

RESULTS AND DISCUSSION

Results from the study are presented in Tables 4.2 and 4.3.

Effect of varying time of second Improvest® dose (fixed-time end point). The effects of varying time of second Improvest® dose were evaluated using Treatments 1, 2, 3, 4, 7, and 10 that had the same fixed-time end point (wk 24 of age). The treatments compared were immunologically-castrated barrows given second dose of Improvest® at either wk 14, 16, 18, or 20 of age and harvested at wk 24 of age, and physically-castrated barrows and gilts harvested at wk 24 of age (Table 4.2).

Growth Performance. Compared to physically-castrated barrows, gilts were lighter ($P \leq 0.05$) at the end of test (wk 24 of age) and had lower ($P \leq 0.05$) overall ADG and ADFI, but greater ($P \leq 0.05$) overall G:F (Table 4.2), results which are in agreement with previous studies (Hamilton et al., 2003; Latorre et al., 2004; Puls et al., 2013b).

Orthogonal contrasts were used to compare the growth performance and carcass characteristics of immunologically-castrated barrows (Treatments 1, 2, 3, and 4 combined) and physically-castrated barrows (Treatment 7). The results of this analysis indicated that immunologically-castrated barrows were heavier ($P \leq 0.05$), and had greater ($P \leq 0.05$) overall ADG than physically-castrated barrows. In addition, overall ADFI was similar ($P > 0.05$) for immunologically- and physically-castrated barrows, but overall G:F was greater ($P \leq 0.05$) for immunologically- compared to physically-castrated barrows. In general, these results are in agreement with most previous research evaluating the growth performance of these 2 genders (Dunshea et al., 2001; Puls et al., 2013a; Puls et al., 2013b).

Of particular interest in the present study was the effect of varying the time of second Improvest® dose on growth performance of immunologically-castrated barrows relative to other genders, particularly the physical castrate. Immunologically-castrated barrows given the second dose at wk 14 and 20 of age grew faster ($P \leq 0.05$) than physically-castrated barrows, with immunologically-castrated barrows given the second dose at wk 16 and 18 of age being intermediate and not different ($P > 0.05$) from the other treatments for growth rate (Table 4.2). Immunologically-castrated barrows given the second dose early (i.e., at either wk 14 or 16) had similar ($P > 0.05$) ADFI and G:F as physically-castrated barrows, however, immunologically-castrated barrows given second dose at wk 18 and 20 of age had lower ($P \leq 0.05$) ADFI, but greater ($P \leq 0.05$) G:F, than physically-castrated barrows. In actual fact, giving the second Improvest® dose 4-wk prior to end of test resulted in the greatest ($P \leq 0.05$) overall G:F compared to the other treatments.

Prior to the second Improvest® dose, immunologically-castrated barrows are similar physiologically to intact males (Millet et al., 2011), which have been shown to consume less feed, grow similar or slower, and have greater feed efficiency compared to physical castrates (Charette, 1961; Prescott and Lamming, 1964; Dunshea et al., 2001). It has also been well documented that in the period from the second Improvest® dose to harvest weight, the growth rate and feed intake of immunologically-castrated barrows increases dramatically and is generally greater than that of physical castrates (Dunshea et al. 2001; Puls et al., 2013a; Puls et al., 2013b). In theory, therefore, as the period between second Improvest® dose and end of test increases, the relative growth performance of immunologically-castrated barrows and physically-castrated barrows should change. Relative to the physically-castrated barrows, growth rate and feed intake of immunologically-castrated barrows should increase and feed efficiency should decrease, as animals spend a longer time as immunological castrates than as intact males. The results of the present study are partly in agreement with this concept. Feed intake and feed efficiency of immunologically-castrated barrows given second Improvest® dose early (i.e., at 10- and 8-wk prior to end of test) were similar to physically-castrated barrows, whereas for immunologically-castrated barrows given second Improvest® dose late (i.e., at 6- and 4-wk prior to end of test), feed intake was lower, but feed efficiency was greater, than for physically-castrated barrows (Table 4.2). The exception to this concept was for growth rate where there was no effect of time of second dose and, in addition, the differences between physically-castrated barrows and the immunologically-castrated barrows treatments was relatively small and inconsistent (Table 4.2).

The only published study to evaluate the impact of increasing the time of second Improvest® dose on growth performance is that of Lealiifano et al. (2011) in which the second Improvest® dose was given at 2, 3, 4, or 6 wk prior to end of test which was at wk 22 of age. In that study, there was no effect of time between second Improvest® dose and end of test on overall growth rate, results that are similar to the present study. However, in contrast to the results of the current study, Lealiifano et al. (2011) found that overall feed intake increased linearly, with no change in feed efficiency, as the time between second dose and end of test increased. Further research is needed to clarify the relationship between growth performance and time of the second Improvest® dose relative to end of test.

The results presented in Table 4.2 are for the 15 week growth period from week 9 to 24 of age. For the immunologically-castrated barrow treatments, this combines the periods before and after the second Improvest® dose, which varied between immunologically-castrated barrow treatments and this makes interpretation of these results difficult. Nevertheless, these results suggest no benefit in terms of growth rate and a substantial disadvantage for feed efficiency from giving the second Improvest® dose any earlier than 4 weeks prior to the end of test.

Carcass Characteristics. Gilts were lighter ($P \leq 0.05$) at harvest and had lower ($P \leq 0.05$) hot carcass weight than physically-castrated barrows (Table 4.2). There was no difference ($P > 0.05$) in carcass yield or on last rib backfat thickness between gilts and physically-castrated barrows. The differences reported in the literature for carcass yield between physically-castrated barrows and gilts are relatively inconsistent. For example, some studies have shown carcass yield to be greater for physically-castrated barrows compared to gilts (Fàbrega et al., 2010), others have reported no difference in carcass yield between the 2 genders (Gispert et al., 2010, Morales et al., 2010; Puls et al., 2013b), and some studies have shown a greater carcass yield for gilts compared to physically-castrated barrows (Ellis et al., 1996; Latorre et al., 2004; Morales et al., 2013). In contrast to the results of the present study, most studies have reported lower backfat thickness for gilts compared to physically-castrated barrows (Fàbrega et al., 2010; Morales et al., 2010; Font-i-Furnols et al., 2012). However, in the present study, both carcass yield and backfat depth were numerically lower for gilts than physically-castrated barrows (Table 4.2).

The results of the orthogonal contrasts indicated that immunologically-castrated barrows were heavier ($P \leq 0.05$) at time of slaughter compared to physically-castrated barrows. Hot carcass weight was similar ($P > 0.05$) for immunologically- and physically-castrated barrows, however, carcass yield was lower ($P \leq 0.05$) for immunologically-castrated barrows (Table 4.2), results which agree with previous studies (Boler et al., 2013; Puls et al., 2013b). Similar to other studies (D'Souza and Mullan, 2003; Fàbrega et al., 2010; Puls et al., 2013b), there was no difference ($P > 0.05$) in backfat thickness between immunologically- and physically-castrated barrows.

Boler et al. (2013) showed that the major causes of the reduced carcass yield in immunologically- compared to physically-castrated barrows were increased weight of reproductive tract and testicles, gut fill and gut tissue, and organs (particularly the kidney and liver). In theory, as the period between second Improvest® dose and harvest increases, differences between immunologically- and physically-castrated barrows for all of these components should decrease as the regression in the size of the reproductive tract and associated tissues continues and the initial increase in feed intake in immunologically- relative to physically-castrated barrows starts to decrease. Consequently, it would be expected that the difference in carcass yield between physically- and immunologically-castrated barrows would decrease with increasing time from second Improvest® dose to harvest. In the present study, carcass yield was numerically higher for immunologically-castrated barrows given the second Improvest® dose at wk 14 (~0.7% units) and 16 (~0.9% units) of age compared to those at wk 18 and 20 of age, however, the differences between immunologically-castrated barrow treatments were not statistically significant ($P > 0.05$). These results are similar to the study by Lealiifano et al. (2011) which reported no significant effect of time of second Improvest® dose on carcass yield, although carcass yield in that study was numerically higher for immunologically-castrated barrows given the second Improvest® dose earlier compared to later in the growth period.

Similarly, there was no effect ($P > 0.05$) of timing of second Improvest® dose on last rib backfat thickness, results which are in contrast to Lealiifano et al. (2011), which reported increased backfat thickness as the period between second Improvest® dose and harvest weight increased. However, in that study, pigs were harvested at much lighter weights than in the current study (~105 kg vs. 135 kg), which makes comparison of these results difficult.

Effect of increasing the time from second Improvest® dose to end of test (variable time end points). To evaluate the effects of extending the time after second Improvest® dose on growth and carcass traits, immunologically-castrated barrows were given the second dose at 20 wk of age and taken off test and sent for harvest at 24, 26, or 28 wk of age (Treatments 4, 5, and 6, respectively). Physically-castrated barrows (Treatments 7, 8, and 9, respectively) and gilts (Treatments 10, 11, and 12, respectively) were also taken off test and sent for harvest at 24, 26, and 28 wk of age.

Growth Performance. Least squares means for the effect of age at end of test on growth performance of the 3 genders are presented in Table 4.3 with the results for ADG, ADFI, and G:F being illustrated in Figures 4.1, 4.2, and 4.3, respectively.

Gilts that completed test at 24 and 26 wk of age, but not at 28 wk of age, were lighter ($P \leq 0.05$) and had lower ($P \leq 0.05$) overall ADG than physically-castrated barrow (Table 4.3). There was no effect ($P > 0.05$) of age at end of test on overall ADG of gilts, however, for physically-castrated barrows, overall growth rate generally declined with age at end of test (Fig. 4.1). In addition, gilts had lower ($P \leq 0.05$) overall ADFI and greater ($P \leq 0.05$) overall G:F than physically-castrated barrows at each of the 3 ages at end of test (Table 4.3). Overall feed efficiency declined at a greater rate for physically-castrated barrows than gilts (Fig. 4.3). These differences in growth performance between gilts and physical castrates are generally similar to those of the fixed-time comparison discussed previously and those of other studies (Hamilton et al., 2003; Latorre et al., 2004; Puls et al., 2013b).

For each of the 3 age at end of test treatments, immunologically-castrated barrows were heavier (7.9, 9.8, and 9.5 kg for the wk 24, 26, and 28 treatments, respectively; $P \leq 0.05$) and had greater ($P \leq 0.05$) overall ADG (7.9, 8.5, 5.9% for the wk 24, 26, and 28 treatments, respectively; $P \leq 0.05$) than physically-castrated barrows (Table 4.3). In addition, the difference between these genders for overall ADG generally decreased with increasing age at end of test (Fig. 4.1). Overall ADFI was similar ($P > 0.05$), but overall G:F was greater ($P \leq 0.05$), for immunologically- than physically-castrated barrows at each of the 3 ages at end of test time points (Table 4.3). However, the difference in feed efficiency between the 2 genders decreased as the time between second Improvest® dose and end of test increased (12.5%, 9.9%, and 7.1% for wk 24, 26, and 28 end of test time points, respectively; Fig. 4.3). These results suggest that immunologically-castrated barrows had greater ADG and G:F compared to physically-castrated barrows, but that the growth performance advantages of immunologically-castrated barrows relative to physically-castrated barrows decrease as the time between second Improvest® dose and end of test increases beyond 4 wk, results which agree with those of the fixed-time study period evaluation discussed previously.

Carcass Characteristics. Least squares means for the effect of age at end of test on carcass measures of the 3 genders are presented in Table 4.3 with the results for carcass yield and last rib backfat thickness for the genders being illustrated in Figures 4.4 and 4.5, respectively. Gilts had lower harvest live weight and hot carcass weight than physically-castrated barrows at wk 24 and 26, but not at wk 28 of age at end of test (Table 4.3). There was no effect of age at end of test for carcass yield; gilts had lower backfat depth than physically-castrated barrows at 28 wk but not at the other ages (Table 4.3). The differences in carcass measures between gilts and physically-castrated barrows are generally in agreement with those of the fixed-time comparison discussed previously and with most previous research (Morales et al., 2010; Font-i-Furnols et al., 2012).

Immunologically-castrated barrows were heavier ($P \leq 0.05$), but had lower ($P \leq 0.05$) carcass yield than physically-castrated barrows at all age at end of test time points (Table 4.3), results which agree with most previous research evaluating these 2 genders (Boler et al., 2013; Puls et al., 2013b). However, the difference between the genders for carcass yield declined as the time between second Improvest® dose and harvest increased (Fig. 4.4). For example, at 4 wk after second Improvest® dose (i.e., wk 24 of age), physically-castrated barrows had 1.8 percentage unit greater ($P \leq 0.05$) carcass yield than immunologically-castrated barrows. However, at 8-wk after second Improvest® dose (i.e., wk 28 of age), the difference in carcass yield between the 2 genders was reduced to 1.0 percentage unit (Fig. 4.4). These results suggest that the reduction in carcass yield for immunologically-castrated barrows can be reduced by increasing the time between second Improvest® dose and harvest weight.

There was no difference ($P > 0.05$) in last rib backfat thickness between immunologically- and physically-castrated barrows at any of the age at end of test time points (Table 4.3), however, for both genders, backfat thickness increased with age (Fig. 4.5). These results are generally similar to that of other studies (D'Souza and Mullan, 2003; Puls et al., 2013b).

Similar to the results of the fixed-time study period evaluation discussed previously (Table 4.2), these results suggest a substantial disadvantage in growth performance, particularly feed efficiency, from extending the period between the second Improvest® dose beyond 4 wk. However, the difference in carcass yield in immunologically- relative to physically-castrated barrows may be reduced by increasing the time between second dose and harvest beyond 4 weeks.

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TABLES

Table 4.1. Diet formulations and calculated composition.

	Dietary phase				
Item	1	2	3	4	5
Amount of feed delivered/pig, kg:	40.0	52.3	63.3	56.7	To end of study[1]
Ingredient, %					
Corn	63.93	69.71	75.38	78.68	80.15
Soybean meal	33.06	27.53	22.13	18.95	17.49
Dical	1.20	1.01	0.82	0.72	0.73
Limestone	0.86	0.84	0.82	0.81	0.80
Salt	0.53	0.53	0.53	0.53	0.53
Lysine	0.15	0.15	0.15	0.15	0.15
Methionine-DL	0.10	0.07	0.03	0.01	0.01
Threonine	0.04	0.05	0.05	0.05	0.04
Trace mineral premix[2]	0.10	0.09	0.08	0.08	0.08
Vitamin premix[3]	0.03	0.03	0.03	0.03	0.03
Calculated composition, %					
Crude protein	21.10	18.85	16.63	15.33	14.72
Crude fat	2.38	2.47	2.56	2.61	2.64
Crude fiber	1.74	1.72	1.71	1.70	1.70
ADF	3.15	3.05	2.95	2.89	2.86
NDF	6.28	6.29	6.30	6.30	6.30
Ca	0.73	0.66	0.59	0.56	0.55
P, total	0.61	0.55	0.5	0.47	0.46
Na	0.22	0.22	0.22	0.22	0.22
Lysine, total	1.27	1.12	0.97	0.89	0.85
Lysine, digestible	1.12	0.99	0.85	0.77	0.74
ME, Kcal/kg	3,277	3,279	3,281	3,281	3,281

[1]Phase 5 was fed from end of phase 4 to the end of the study.
[2]Provided per kg of final diet: iron, 124 mg as iron sulfate; zinc, 124 mg as zinc oxide; manganese, 29 mg as manganese sulfate; copper, 12 mg as copper sulfate; iodine, 0.2 mg as calcium iodate; and selenium, 0.2 mg as sodium selenite.
[3]Provided per kg of final diet: vitamin A, 4,410 IU; vitamin D3, 689 IU; vitamin E, 22.1 IU; riboflavin, 4.96 mg; vitamin B12, 0.02 mg; menadione, 1.27 mg; D-pantothenic acid, 17.9 mg; and niacin, 20.9 mg.

Table 4.2. Least squares means for the effects of age at end of test relative to time of second Improvest® dose for immunologically-castrated barrows in comparison to physically-castrated barrows and gilts on growth performance and carcass characteristics (fixed-time end).

Treatment:	1	2	3	4	7	10						
Gender[1]:	IC	IC	IC	IC	PC	G						
Age at time of second dose[2]:	14	16	18	20	-	-		*P*-values				
Item / Age at end of test[3]:	24	24	24	24	24	24	SEM	Treatment	IC vs. PC[4]	Linear[5]	Quadratic[5]	Cubic[5]
Number of pens	8	8	8	8	8	8	-	-	-			
Growth performance												
BW, kg												
Start (wk 9 of age)	29.5[a]	29.5[a]	29.5[a]	29.5[a]	29.6[a]	28.8[b]	0.44	0.06	0.48	0.47	0.59	0.81
Wk 14	61.4[ab]	61.8[ab]	59.9[bc]	62.1[ab]	62.9[a]	58.3[c]	1.06	0.002	0.07	0.93	0.27	0.09
Wk 16	75.6[ab]	75.6[ab]	73.9[bc]	77.1[a]	77.3[a]	71.5[c]	1.32	0.003	0.16	0.57	0.14	0.17
Wk 18	92.5[a]	91.2[ab]	88.6[b]	91.3[ab]	91.3[ab]	84.3[c]	1.34	<0.001	0.73	0.20	0.08	0.19
Wk 20	109.3[a]	108.1[a]	103.0[b]	107.5[a]	106.7[ab]	98.0[c]	1.56	<0.001	0.85	0.08	0.04	0.03
End of test (wk 24)	138.3[ab]	136.8[ab]	135.1[bc]	139.7[a]	131.8[c]	124.3[d]	1.61	<0.001	0.004	0.67	0.04	0.30
Overall ADG, g	1023[a]	1015[ab]	1003[ab]	1048[a]	971[b]	908[c]	17.1	<0.001	0.01	0.37	0.10	0.38
Overall ADFI, kg	2.93[a]	2.97[a]	2.77[b]	2.77[b]	2.89[a]	2.53[c]	0.047	<0.001	0.45	0.001	0.68	0.02
Overall G:F, kg:kg	0.350[bc]	0.343[c]	0.363[b]	0.378[a]	0.336[c]	0.358[b]	0.0052	<0.001	<0.001	<0.001	0.02	0.12
Carcass characteristics												
Harvest live weight, kg[6]	138.3[a]	138.4[a]	135.1[ab]	139.7[a]	131.8[b]	124.2[c]	1.76	<0.001	0.003	0.87	0.15	0.11
Hot carcass weight, kg	101.9[a]	102.3[a]	98.6[a]	102.1[a]	98.7[a]	92.3[b]	1.44	<0.001	0.11	0.61	0.23	0.07
Carcass yield, %	73.7[bc]	73.9[bc]	73.0[c]	73.1[c]	74.9[a]	74.3[ab]	0.32	0.001	<0.001	0.08	0.85	0.19
Last rib backfat depth, mm	23.1	23.3	21.6	22.6	21.9	19.9	1.63	0.54	0.63	0.63	0.78	0.46

[a,b,c,d]Means within a row with different superscripts are different ($P \leq 0.05$).

[1]Gender: IC = Immunologically-castrated barrow; PC = Physically-castrated barrow; G = Gilt.

[2]Age at time of second dose: Refers to timing of second Improvest® dose and is expressed in weeks of age.

[3]Age at end of test: Expressed in weeks of age.

[4]Means were compared using orthogonal contrasts.

[5]Orthogonal polynomial contrasts were conducted to evaluate effects of time of second dose for immunologically-castrated barrow treatments only.

[6]Harvest live weight does not include final farm live weights of pigs in which carcass data was not collected.

Table 4.3. Least squares means for the effects of age at end of test relative to time of second Improvest® dose for immunologically-castrated barrows in comparison to physically-castrated barrows and gilts on growth performance and carcass characteristics (variable end-time points).

Treatment:	4	5	6	7	8	9	10	11	12		
Gender[1]:	IC	IC	IC	PC	PC	PC	G	G	G		
Age at time of second dose[2]:	20	20	20	-	-	-	-	-	-		
Item Age at end of test[3]:	24	26	28	24	26	28	24	26	28	SEM	*P*-value
Number of pens	8	8	8	8	8	8	8	8	8	-	-
Growth performance											
BW, kg											
Start (wk 9 of age)	29.5^{ab}	29.5^{ab}	29.4^{ab}	29.6^{a}	29.6^{a}	29.6^{a}	28.8^{b}	28.8^{b}	28.8^{b}	0.45	0.04
Time of 2nd dose (wk 20)	107.5^{a}	106.9^{a}	106.2^{a}	106.7^{a}	106.8^{a}	105.9^{a}	98.0^{b}	98.4^{b}	99.5^{b}	1.44	<0.001
End of test	139.7^{ef}	153.6^{b}	161.9^{a}	131.8^{g}	143.8^{de}	152.4^{bc}	124.3^{h}	136.0^{fg}	148.0^{cd}	1.76	<0.001
Overall ADG, g	1048^{a}	1039^{a}	975^{b}	971^{b}	958^{bc}	921^{cd}	908^{d}	901^{d}	895^{d}	15.4	<0.001
Overall ADFI, kg	2.77^{bc}	2.93^{a}	2.93^{a}	2.89^{ab}	2.98^{a}	2.96^{a}	2.53^{d}	2.61^{d}	2.63^{cd}	0.055	<0.001
Overall G:F, kg:kg	0.378^{a}	0.355^{bc}	0.333^{ef}	0.336^{de}	0.323^{fg}	0.311^{g}	0.358^{b}	0.345^{cd}	0.340^{de}	0.0051	<0.001
Carcass characteristics											
Harvest live weight, kg[4]	139.7^{e}	153.6^{b}	160.7^{a}	131.8^{f}	145.5^{d}	152.0^{bc}	124.3^{g}	136.7^{ef}	148.0^{cd}	1.98	<0.001
Hot carcass weight, kg	102.1^{de}	113.8^{b}	120.2^{a}	98.7^{e}	109.7^{c}	115.2^{b}	92.2^{f}	102.8^{d}	111.9^{bc}	1.57	<0.001
Carcass yield, %	73.1^{d}	74.1^{c}	74.8^{bc}	74.9^{bc}	75.4^{ab}	75.8^{a}	74.3^{c}	75.2^{ab}	75.6^{ab}	0.29	<0.001
Last rib backfat, mm	22.5^{cd}	26.2^{abc}	26.7^{a}	21.8^{d}	26.3^{ab}	27.3^{a}	19.8^{d}	23.0^{bcd}	22.8^{cd}	1.32	0.001

[a,b,c,d,e,f,g,h]Means within a row with different superscripts are different ($P \leq 0.05$).

[1]Gender: IC = Immunologically-castrated barrow; PC = Physically-castrated barrow; G = Gilt.

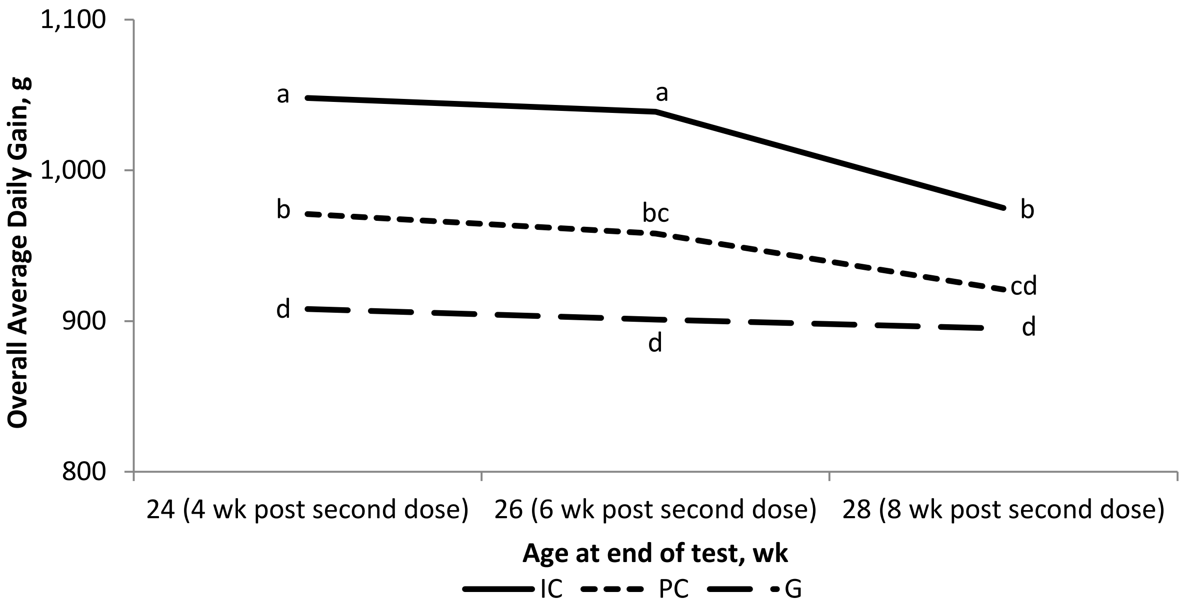
[2]Age at time of second dose: Refers to timing of second Improvest® dose and is expressed in weeks of age.

[3]Age at end of test: Expressed in weeks of age.

[4]Harvest live weight does not include final farm live weights of pigs in which carcass data was not collected.

FIGURES

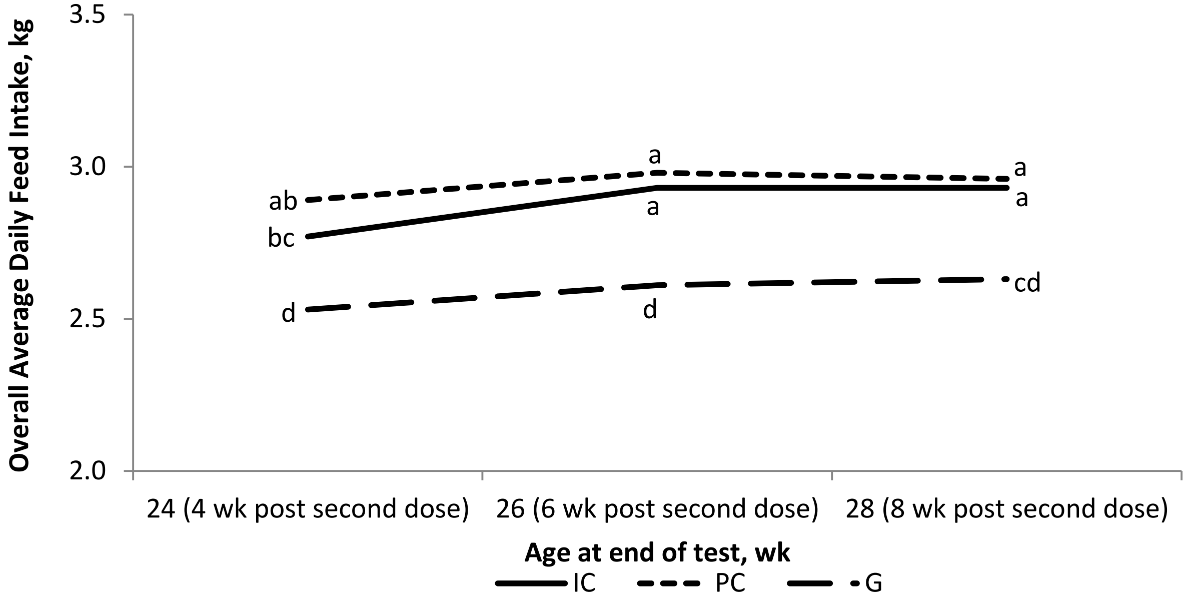
Figure 4.1. Effects of Gender and Age at End of Test on Overall Average Daily Gain.



[a,b,c,d]Means with different superscripts are different ($P \leq 0.05$).

Gender: IC = Immunologically-castrated barrow; PC = Physically-castrated barrow; G = Gilt.

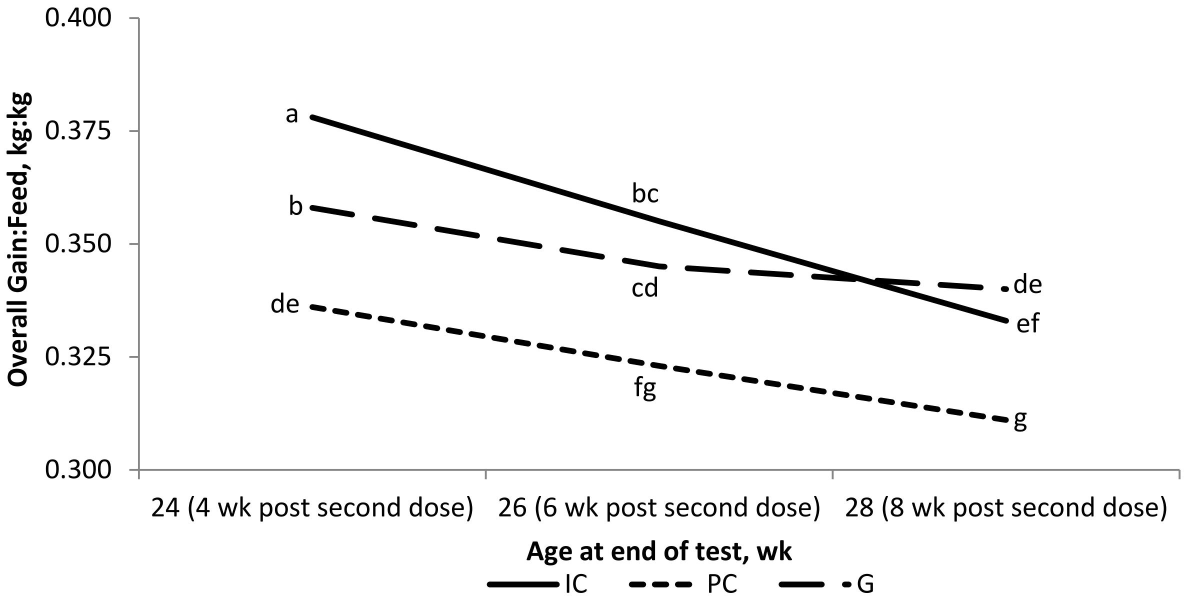
Figure 4.2. Effects of Gender and Age at End of Test on Overall Average Daily Feed Intake.



[a,b,c,d]Means with different superscripts are different ($P \leq 0.05$).

Gender: IC = Immunologically-castrated barrow; PC = Physically-castrated barrow; G = Gilt.

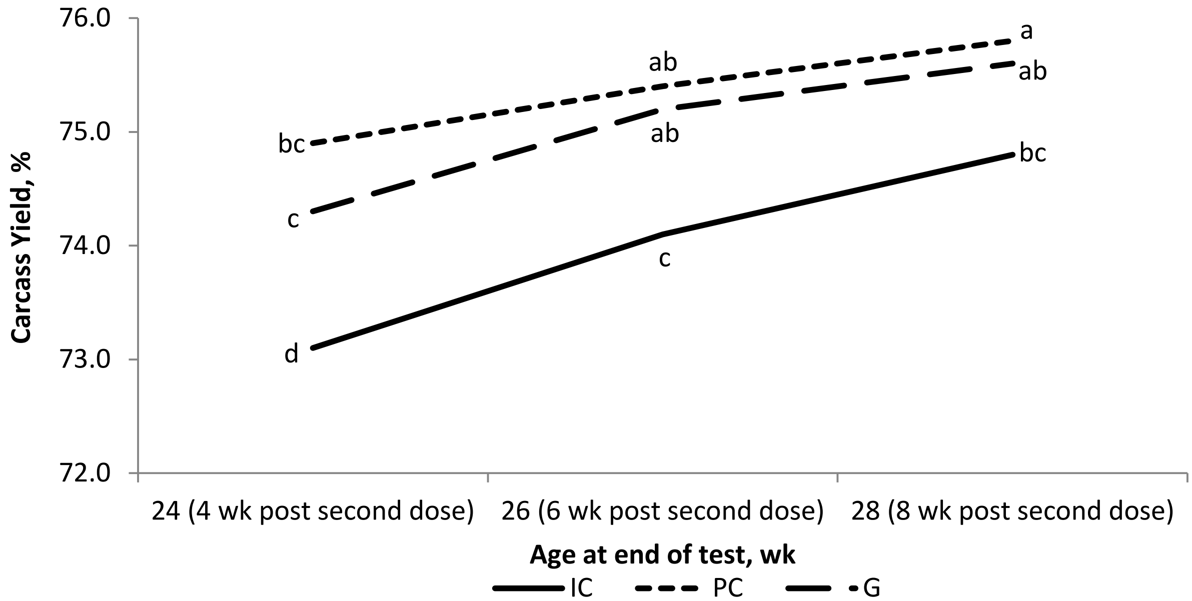
Figure 4.3. Effects of Gender and Age at End of Test on Overall Gain:Feed Ratio.



[a,b,c,d,e,f,g]Means with different superscripts are different ($P \leq 0.05$).

Gender: IC = Immunologically-castrated barrow; PC = Physically-castrated barrow; G = Gilt.

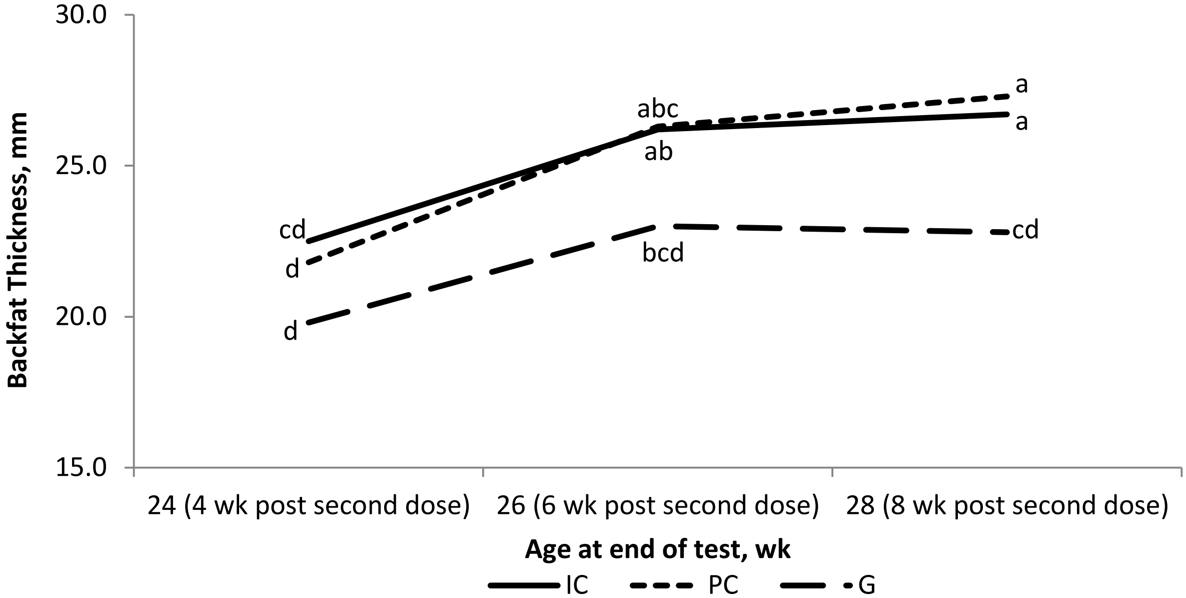
Figure 4.4. Effects of Gender and Age at End of Test on Carcass Yield.



[a,b,c]Means with different superscripts are different ($P \leq 0.05$).

Gender: IC = Immunologically-castrated barrow; PC = Physically-castrated barrow; G = Gilt.

Figure 4.5. Effects of Gender and Age at End of Test on Last Rib Backfat Thickness.



[a,b,c,d]Means with different superscripts are different ($P \leq 0.05$).

Gender: IC = Immunologically-castrated barrow; PC = Physically-castrated barrow; G = Gilt.